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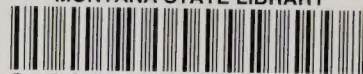
IRRIGATION SALINITY STUDY
ON THE POWDER RIVER



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DETERMINATION OF MAXIMUM TOLERABLE SALINITY LEVELS
FOR CONTINUOUS IRRIGATION ON VARIOUS SOILS
ALONG THE POWDER RIVER

Report to the Water Quality Management Project

Yellowstone - Tongue A.P.O.

Broadus, Montana

By

C. J. deMooy and W. T. Franklin

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Determination of Maximum Tolerable Salinity Levels

For Continuous Irrigation on Various Soils

Along the Powder River

I. Objectives.

1. To determine the maximum salinity of water pumped from the Powder River that can be tolerated for continuous irrigation without a decrease in crop yield.
2. To specify maximum tolerable salinity limits for the most common soil type currently under irrigation, and for the soil type with the most severe limitations.
3. To determine the maximum salinity that can be tolerated for a period of one year assuming that normal salinity levels prevailed during the previous year and the year following.
4. Other water quality factors which may limit the use of water for continuous irrigation.
5. To specify special management practices which can be followed to prevent reduction in crop yield.

II. General Procedure.

The contract activities call for an interpretative study on soil and irrigation water analyses supplied by YTAPO.

1. Soils data. Results on chemical analysis performed by Montana Testing Laboratories on soil samples collected from 32 irrigated soils and 17 non-irrigated companion profiles were provided by the Water Quality Management Project Office. The data were converted into suitable units for evaluation of soil salinity and reproduced in that form with this report (milliequivalents per liter in soil saturation extract). Further conversion from saturation extract to a field capacity basis were made using relationships developed by Lonkerd and Donovan¹.

2. Water quality averages. U.S. Geological Survey data (U.S. Geological Survey, 1949-1976) for Moorehead, Montana were used as the basis for calculating average values for different parameters such as EC, SAR, Ca, Ca:Mg, Na, K, HCO₃, SO₄ and Cl. Complete analyses of composited water samples of the Powder River taken at Moorehead were available for 1951, 1952, 1953, 1956, and 1957. Complete or mostly complete analyses were available for samples taken at monthly intervals from 1970-1976 along with instantaneous discharge data.

¹Lonkerd, W. E. and T. J. Donovan. Unpublished data.

It was assumed that irrigation was applied in May, July, and September where three irrigations were made. For one irrigation, it was assumed that it was applied in May. For an average conductivity value of each month, a long-term average was desirable. More conductivity data were available for the Powder at Arvada and Clear Creek than at Moorehead. Therefore, regression equations were developed for making estimations of conductivity from discharge data along with other parameters for these branches of the Powder. Other parameters used for the Powder at Arvada for May (only) were ratio of Powder at Kaycee/Powder at Arvada and runoff of the previous season. Runoff of the previous season was a parameter in multiple regression equations used for Clear Creek in May, also. A more detailed description was given in a previous report relating to snow pack and water quality relations (Franklin, 1977). For years when no analyses were made at Moorehead, electrical conductivity was estimated as discharge-weighted mixtures and the resulting average of the Powder at Arvada and Clear Creek. These estimates were averaged with available data at Moorehead from 1950-1975 to give a 25-26 year average for May, July, and September.

Equations were developed for ion composition of water at Moorehead by multiple regression of the particular ion with discharge and the ratio of discharge of Powder at Arvada to Clear Creek. Analyses of K and HCO_3 for samples taken at Locate were also included because these ions were very similar at the two different locations. A regression equation was developed for estimating total ion concentration from individual electrical conductivity measurements. Calcium, Ca:Mg, K, HCO_3 , Cl, and SAR were calculated as 25 year averages with the complete data in 1951, 1952, 1953, 1956, and 1957 and with values estimated from discharge at Moorehead and ratio of Powder at Arvada to Clear Creek.

3. Crop evapotranspiration. Potential evapotranspiration was determined from published weather records and solar radiation data using the Jensen-Haise equation (Jensen, M. E. and H. R. Haise, 1963). The equation is as follows:

$$\text{ETp} = C_T (T - T_x) R_s$$

where: ETp = the potential evapotranspiration for reference crop in inches/day.

C_T = the air temperature coefficient which is constant for a given area and is derived from long-term mean maximum and mean minimum temperatures for the month of highest mean air temperature.

T = mean daily air temperature.

T_x = a constant for a given area is merely the linear equation intercept on the temperature axis in the solar radiation air temperature relationship. The T_x is computed using the equation shown later.

R_s = the daily solar radiation expressed as the equivalent depth of evaporation (inches/day).

$$C_T = \frac{1}{C_1 + C_2 C_H}$$

where $C_1 = 68 - 3.6E/1000$ for T in F°

or $C_1 = 38 - 3.6E/1000$ for T in C°

in which E = the elevation of the area in feet above mean sea level.

$C_2 = 13^\circ F$ or $7.3^\circ C$ depending on the temperature scale used.

C_H = the humidity index and can be calculated by means of the following expressions.

$$C_H = \frac{37.5 \text{ mm Hg}}{e_{s2} - e_{s1}}$$

$$C_H = \frac{50 \text{ mb}}{e_{s2} - e_{s1}}$$

where e_{s2} = the saturation vapor pressure in millibars at the mean maximum air temperature during the warmest month.

e_{s1} = the saturation vapor pressure at mean minimum air temperature during the same month.

T_x can be computed from the expression

$$T_x = 27.5^\circ F - 0.25 (e_{s2} - e_{s1}) F^\circ/\text{mb} - \frac{E}{1000}$$

in which E = the elevation of the area in feet above mean sea level.

Crop coefficients (K_c) were obtained from Jensen (1973) to calculate actual evapotranspiration from ET_p values using the equation

$$ET = K_c \cdot ET_p$$

4. Interpretation of profile salinity for diagnosing past and present irrigation management practices. An important aspect of irrigation management is maintaining a salt balance in the crop root zone. The application of irrigation water in excess of evapotranspiration is necessary to leach soluble salts below the plant root zone and, thus, maintain a favorable salt balance in the root zone. This excess application is called the leaching fraction (LF) and is defined by U.S. Salinity Laboratory Staff (1954) as the fractional volume of irrigation

water (V_{iw}) that leaches through the root zone to become drainage water (V_{dw}) or V_{dw}/V_{iw} . The leaching fraction has also been calculated as: EC_{iw}/EC_{dw} , where EC = electrical conductivity, assuming that EC is directly proportional to total ion concentration, that no dissolution or precipitation of solid phase salts take place and steady state (equilibrium) conditions exist. In practice it is found that determining both V_{iw} and V_{dw} , as well as EC_{dw} , is very difficult under field conditions. Also, irrigation waters containing bicarbonate and sulfate, along with calcium, frequently precipitate as lime or gypsum. When ion precipitation takes place, calculating LF from EC_{iw}/EC_{dw} indicates that leaching is more effective than volume measurements would predict. Dregne (1969) and Pratt, et. al (1972) calculated LF from chloride (Cl) measurements as: Cl_{iw}/Cl_{dw} , where Cl_{dw} was taken as Cl of soil solution at field capacity (FC). Soil-water Cl concentration was calculated as: $Cl_{se} \times SP/FC$, where se = saturated paste (SP) extract. Chloride in the saturated extract can be measured conveniently and Cl absorption by most crops is negligible compared with the total concentration in water. Dregne (1969) and Pratt, et. al (1972) found that LF calculated by Cl determinations in water and soil related very well to volume measurements.

Crops absorb water during the irrigation cycle and leave most of the salt carried by the water in concentrated amounts in the remaining soil solution. When another irrigation is applied, the salts in the soil solution move downward concentrated mainly in the wetting front to the bottom of the root zone. As long as downward movement of irrigation water exceeds upward movement by capillarity, a normal salt distribution is attained in the root zone with a greater salt concentration at the bottom of the root zone than at the soil surface. When a large LF is applied, little concentration occurs at the bottom and below the root zone but when a small LF is applied, a concentration equal to the inverse of the LF is gradually attained and is then considered to be at steady state.

In analyzing soil samples taken from irrigated fields near Broadus, several different types of salinity profiles were found with enough basic differences to warrant a more complete explanation or interpretation of these differences. Types of salinity (EC) and Cl profiles usually found in irrigated soils, including those found near Broadus, are labeled as Type 1 to Type 4 in Figure 1.

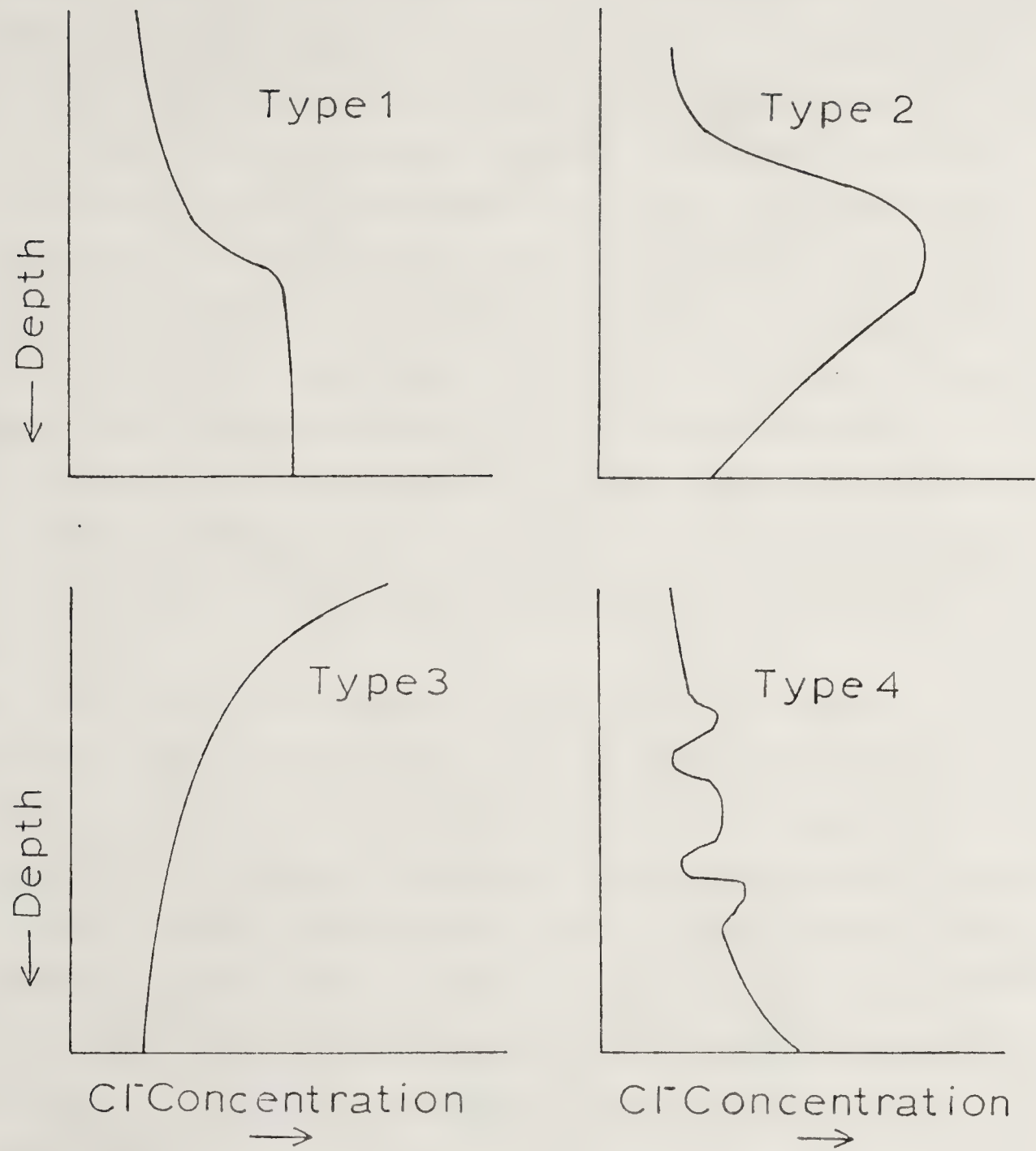


Figure 1. Illustration of types of salt and Cl^- profiles found in irrigated areas.

Type 1 indicates a normal equilibrium distribution of salinity under well-drained (no water table) conditions. Salinity and Cl are low at the soil surface and increase to a maximum at the bottom of the root zone with little change until reaching the capillary fringe of a water table. With shallow-rooted crops such as grass, the increase occurs at a more shallow depth than with deep-rooted crops such as alfalfa.

Type 2 profiles have a maximum accumulation of chlorides within the rooting zone and return to lower concentrations in the deeper substrata. This type indicates that a relatively small leaching fraction is being applied and that the equilibrium state of Type 1 has not been reached. In addition, Type 2 profiles can result under the influence of a seasonal ground water table moving the salts in upward direction and a small leaching fraction which moves salts from the surface down into the accumulation zone. Type 2 profiles possibly could be developed from an initially non-saline soil if an inadequate leaching fraction was applied accompanied by partial leaching due to rainfall sometime during the year. The depth at which the bulge of salt accumulation occurs below the surface depends on the amounts of irrigation water applied. Under extreme conditions the bulge may appear just below the surface layer.

Type 3 represents an inverted profile with salt and Cl content higher at the surface than at greater depths. This type is a result of a high water table where, if irrigated, a salt balance cannot be maintained because upward capillary water movement is greater than the downward gravitational force of applied water.

Type 4, with several small bulges, is characteristic of profiles with textural discontinuities, i.e., alternate layers of fine and sandy materials in the subsoil. Higher concentrations of salt are usually, but not always, found in finer-textured material immediately above and below sandy layers. This is thought to be mainly due to impeded water movement from coarse to fine layers (perched water-table effect) and salt-sieving in finer-textured layers. A frequent cause on sloping land is seepage water from ditches or drainage water from the root zone moving laterally downslope in the more porous coarse-textured layers above confining fine-textured layers. Possibly involved, also, may be some degree of analytical error resulting from over saturation of coarse-textured soil.

III. Climatic Conditions and Consumptive Use of Water.

Temperature and rainfall data are available for Broadus and Miles City, Montana, but no solar radiation records are kept at either location. Therefore, it was necessary to use weather and solar radiation data for calculation of potential evapotranspiration from another station.

1. Temperatures at Broadus. Average monthly temperatures exceeding 32°F generally occur after April 1 but remain below 50°F (Table 1). March temperatures exceed 32° in about 5 out of 10 years but mean monthly temperatures remain below 40° . July and August are the hottest two months with slightly higher temperatures during the month of July. From November 1, monthly temperatures return to the 32° level. January is the coldest month at 16.7° . The mean annual temperature is 44° . It follows that the growing season at Broadus occurs between April 1 and October 31. The consumptive use of water is, therefore, calculated for this period on a monthly basis.

Comparison of mean annual temperatures at Broadus, Montana and at Bismarck, North Dakota, for the period 1967 to 1976, shows a difference of only 3.8° for Bismarck. Most of this difference is due to cooler temperatures at Bismarck during the winter months. The mean monthly temperatures for May, June, July, August, and September differed less than 1° during this 10-year period.

2. Solar radiation. Solar radiation records are available for Great Falls, Montana, and Bismarck, North Dakota. Ten-year data for the period 1962-1971 show differences of 1 to 4 percent between the two stations. The data from Bismarck, North Dakota were used as a basis for calculation of potential evapotranspiration.

3. Precipitation at Broadus. The mean annual rainfall at Broadus is 15.29 inches on the basis of the 10-year period ending 1976 (Table 2). The mean monthly precipitation during the winter months including March is 0.4 to 0.6 inches. The peak of the rainfall distribution occurs during April, May, and June. During this period the monthly rainfall varies between 2.0 and 2.8 inches. A sharp drop in rainfall occurs in July. From July through October, the average monthly rainfall is 1.0 to 1.5 inches. From November onward the precipitation is reduced to the level of that of the winter months (Figure 2). Therefore, three levels occur in the annual rainfall distribution, the highest of which is during spring with more than 2 inches per month. This is followed by the summer and fall periods with about one-half of the monthly rainfall received during spring. The probability of receiving a monthly rainfall exceeding 1 inch during summer and fall is somewhat less than 40 percent.

Table 1. Mean monthly and annual temperatures ($^{\circ}\text{F}$) at Broadus, Montana, for the period 1967 to 1976.

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Mean
Jan.	23.6	17.2	5.2	13.1	14.5	11.9	19.1	20.0	20.8	21.4	16.7
Feb.	29.0	28.2	18.5	29.0	21.8	22.8	27.4	32.6	15.5	32.0	25.7
Mar.	33.2	39.0	26.7	28.9	31.4	37.0	37.2	35.3	28.2	31.1	32.8
Apr.	42.8	41.4	48.7	38.7	45.5	43.6	40.8	46.4	38.9	46.5	43.3
May	50.8	50.4	55.0	55.5	54.2	55.0	52.9	51.1	53.1	56.0	53.4
Jun.	60.9	60.9	58.4	65.3	65.4	65.7	63.9	65.5	61.3	62.4	63.0
Jul.	70.2	69.8	69.5	71.7	65.8	65.1	68.7	73.8	72.5	71.4	69.9
Aug.	68.2	65.6	71.6	71.8	73.2	68.4	70.8	63.5	67.5	68.5	68.9
Sep.	60.3	57.8	61.5	55.6	54.4	55.1	56.8	54.7	55.3	59.6	57.1
Oct.	46.5	45.6	38.4	40.4	43.1	42.0	47.9	48.7	46.1	42.5	44.1
Nov.	32.6	33.0	36.1	31.4	33.6	31.1	29.8	34.8	30.7	30.0	32.3
Dec.	18.8	12.3	24.6	18.7	16.8	15.5	25.1	25.9	26.4	24.4	20.9
Year	44.7	43.5	42.9	43.3	43.3	42.8	45.0	46.0	43.0	45.5	44.0

Table 2. Total monthly and annual precipitation at Broadus, Montana, for the period 1967 to 1976 (inches).

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Mean
Jan.	0.36	0.51	0.44	0.66	1.63	0.58	0.17	0.26	1.65	0.32	0.66
Feb.	0.33	0.30	0.13	0.83	0.67	0.63	0.24	0.22	0.35	0.37	0.41
Mar.	0.52	0.55	0.44	0.58	0.33	0.73	1.30	0.54	0.73	0.43	0.62
Apr.	3.84	0.62	2.91	1.42	1.25	0.94	2.34	2.24	2.54	3.20	2.13
May	1.63	3.08	1.56	4.05	4.26	2.76	1.50	3.04	3.08	2.52	2.75
Jun.	3.90	3.91	2.56	1.51	1.25	3.88	2.12	0.68	3.66	4.24	2.77
Jul.	0.86	0.68	1.40	0.97	0.19	2.21	0.08	2.81	0.41	0.67	1.03
Aug.	0.01	3.11	0.36	0.16	0.38	1.64	1.02	0.60	1.13	2.58	1.10
Sep.	4.55	0.83	0.04	1.38	1.38	1.07	2.31	0.68	0.06	0.45	1.28
Oct.	0.94	0.73	0.95	0.65	5.86	0.93	1.30	1.23	0.94	0.98	1.45
Nov.	0.47	0.85	0.36	1.07	0.62	0.07	0.22	0.37	0.53	0.38	0.49
Dec.	0.50	1.54	0.56	0.39	0.35	0.57	0.61	0.21	0.97	0.27	0.60
Year	17.91	16.71	11.71	13.67	18.17	16.01	13.21	12.88	16.05	16.41	15.29

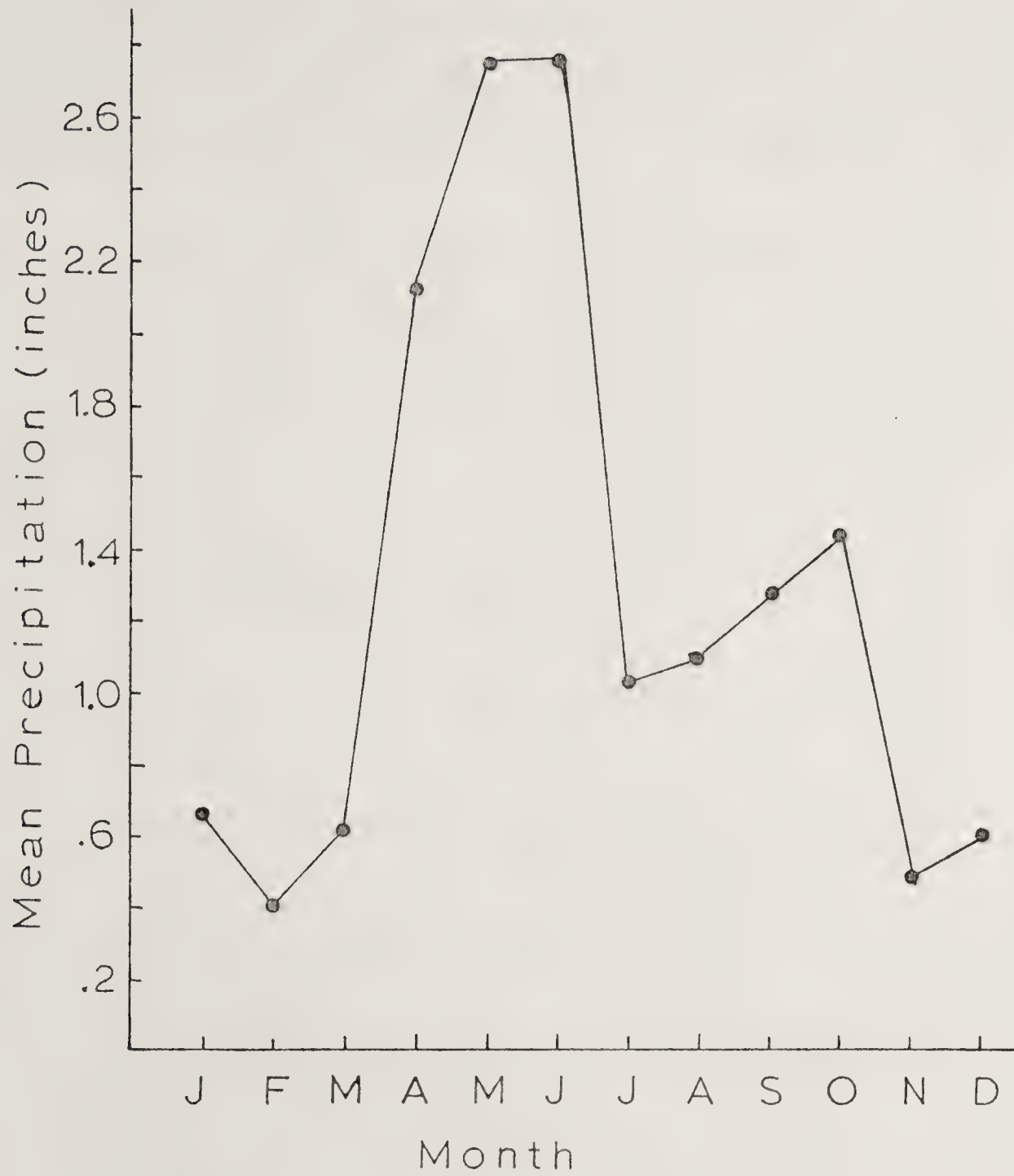


Figure 2. Mean monthly precipitation at Broadus, Montana, based on a 10-year period, 1967-1976.

4. Consumptive use of water. Calculation of potential evapotranspiration using the procedures outlined in Section II, 3 and data from Bismarck, North Dakota resulted in the values summarized in Table 3. The calibrated Jensen-Haise equation was the following: $ET_p = 0.0129 (T - 17.97) R_s$. Cumulative potential evapotranspiration rates were calculated and are presented in Table 4. The means of these values are proposed as the best available estimate of potential evapotranspiration (ET_p) for the Powder River Valley area (Table 5). The ET_p values obtained in this manner were converted into actual evapotranspiration rates (ET_a) or consumptive use of water for the various crops in the area by application of crop coefficients published by Jensen (1973). The ET_a rates are presented as simple monthly values (Table 6) and cumulative values (Table 7).

Table 3. Potential evapotranspiration for the period April 1 to October 31 during the years 1962 to 1971 at Bismarck, North Dakota (inches/day).

Month	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Apr.	0.111	0.085	0.098	0.065	0.064	0.066	0.104	0.116	0.082	0.098
May	0.128	0.163	0.183	0.149	0.166	0.169	0.145	0.185	0.159	0.175
Jun.	0.243	0.254	0.190	0.202	0.229	0.211	0.188	0.202	0.297	0.239
Jul.	0.246	0.275	0.264	0.249	0.253	0.312	0.278	0.237	0.308	0.288
Aug.	0.247	0.233	0.195	0.205	0.180	0.247	0.214	0.282	0.268	0.279
Sep.	0.141	0.134	0.115	0.067	0.131	0.157	0.138	0.162	0.138	0.125
Oct.	0.075	0.091	0.070	0.081	0.063	0.056	0.062	0.041	0.060	0.056

Table 4. Cumulative potential evapotranspiration during the season April 1 to October 31 of the years 1962 to 1971 at Bismarck, N.D. (inches).

Month	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Apr.	3.32	2.56	2.95	1.95	1.93	1.97	3.13	3.48	2.46	2.95
May	7.28	7.60	8.62	6.56	7.07	7.20	7.61	9.21	7.40	8.38
Jun.	14.58	15.21	14.33	12.63	13.94	13.52	13.26	15.28	16.30	15.54
Jul.	22.20	23.73	20.52	20.36	21.77	23.18	21.88	22.61	25.86	24.46
Aug.	29.87	30.96	26.55	26.72	27.34	30.82	28.51	31.37	34.16	33.12
Sep.	34.11	34.97	30.01	28.73	31.28	35.54	32.65	36.22	38.29	36.86
Oct.	36.42	37.78	32.19	31.24	33.24	37.28	34.57	37.50	40.15	38.58

Table 5. Mean monthly potential evapotranspiration for the period April 1 to October 31 at Bismarck, North Dakota, 1962-1971.

Month	ETp (Inches per Month)	Cumulative ETp (Inches)
April	2.64	2.64
May	5.05	7.69
June	6.69	14.38
July	8.59	22.97
August	7.25	30.22
September	3.87	34.09
October	2.02	36.11

Table 6. Actual monthly evapotranspiration values for corn, pasture, and alfalfa calculated from 10 years of climatic data from Bismarck, North Dakota, and crop coefficients from Jensen (1973), inches per month.

Month	Corn	Pasture	Alfalfa (new stand)*	Alfalfa (old stand)*		
				1	2	3
April	--	2.30	--	2.64	2.64	2.64
May	1.31	4.39	--	5.05	5.05	5.05
June	3.88	5.83	--	6.69	6.69	6.69
July	7.90	7.47	--	6.44	6.44	6.44
August	6.74	6.31	3.05	7.25	5.44	5.44
September	2.24	3.37	2.96	3.87	3.87	3.23
October	0.48	1.76	2.02	2.02	2.02	1.85

* = Established without nurse crop.

1 = Assuming first cutting is June 30 and left for seed production.

2 = Assuming first cutting is June 30, second cutting is in August, followed by grazing.

3 = Assuming a third cutting in late September.

Table 7. Cumulative monthly actual evapotranspiration values for corn, pasture, and alfalfa calculated from 10 years of climatic data from Bismarck, North Dakota, and crop coefficients from Jensen (1973), inches.

Month	Corn	Pasture	Alfalfa (new stand)*	Alfalfa (old stand)		
				1	2	3
April	--	2.30	--	2.64	2.64	2.64
May	1.31	6.69	--	7.69	7.69	7.69
June	5.19	12.51	--	14.38	14.38	14.38
July	13.09	19.98	--	20.82	20.82	20.82
August	19.83	26.29	3.05	28.07	26.26	26.26
September	22.07	29.66	6.01	31.94	30.10	29.49
October	22.55	31.42	8.03	33.96	32.12	31.34

* = Established without nurse crop.

1 = Assuming first cutting is June 30 and left for seed production.

2 = Assuming first cutting is June 30, second cutting is in August, followed by grazing.

3 = Assuming a third cutting is in late September.

IV. Interpretation of Soil Salinity Profiles.

Thirty two profiles from irrigated land located at three ranches in the Powder River Valley were chemically analyzed. Data from 17 companion sites on non-irrigated land are also available.

1. Description and interpretation of salt distribution in individual fields and soil profiles.

a. The Jurica brome grass pasture area (Jg).

The irrigated field is divided in two parts by a soil boundary. The upper portion, adjoining the irrigation ditch consists of Heldt silty clay loam. Two soil profiles were sampled in this area to a depth of 8 to 9 feet (Jg 1 and 4). Two more profiles from unirrigated sites located just across the supply ditch were sampled to provide a comparison with the irrigated land (Jg 1C and Jg 4C).

The lower portion of the field consists of Haverson silty clay. Three profiles were samples in this area (Jg 2, 3, and 5) and one companion profile in an unirrigated field of the same soil type located across the road (Jg 5C).

The 2 profiles Jg 1 and Jg 4 in Heldt soils are chemically very similar. Both have low conductivity: Jg 1 less than 1.5 mmhos/cm to its full depth of 9 feet; Jg 4 less than 2.7 mmhos/cm (Table 8). The upper portion of this field has, therefore, no salt problems. The similarity between the 2 sites is further substantiated by the Sodium Adsorption Ratios (SAR) of the saturation extracts. Profile Jg 1 has SAR values between 3 and 5 which indicates absence of sodium problems and Jg 4 is comparable with a maximum SAR value of 6.0 at 4-5 feet depth. Both profiles have relatively low and uniform chloride ion concentrations which indicate good water relationships and free downward movement. The ratios of chlorides in the saturation extract of surface and subsoil layers show a moderate accumulation of chlorides through the rooting zone (Table 9). Calcium carbonate precipitation probably occurs throughout both profiles, but sulfate concentrations are low and indicate absence of precipitated gypsum.

The companion profiles Jg 1C and Jg 4C add only little new information. Jg 1C shows an increase in SAR below a depth of 4 feet, reaching sodic levels below 6 feet. At the same time, the EC values indicate salinity in the soil below 4 feet whereas high calcium, magnesium and sulfate concentrations prove the presence of precipitated gypsum. The chemical data of profile Jg 1C may indicate the natural conditions with unfavorable saline and sodic features below a depth of approximately 6 feet. On the other hand, this companion profile is located too closely to the water supply ditch which may have resulted in an unnatural subsoil enrichment in salts and sodium from lateral seepage.

Profile Jg 4 shows favorable chemical conditions to its full depth of 10 feet. The soil solution, however, would be saline at field capacity below 4 feet. The interpretation of the favorable chemistry does not carry much weight, since the site of the profile is extremely close to a soil boundary delineating an area with sandstone outcrops. The sandy subsoil of Jg 4 would assist in preventing the subsoil chemistry of profile Jg 1.

In contrast with the favorable soil conditions in the upper portion of the field, the lower area has poor moisture relations, and a serious sodicity problem at a depth of 1 foot. Starting with profile Jg 2, the EC of the saturation extract increases from 5 to 10 mmhos/cm in the first 5 feet of the profile and to even greater values below that (Table 8). This means a development of progressively more saline conditions with depth. Furthermore, SAR values of 14 to 20 in the saturation extract occur between a depth of 1 and

Table 8. Physical and chemical analysis of irrigated and non-irrigated companion soil profiles.

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Jg 1											
0-1	7.9	1.2	3.5	65	4.62	1.85	6.31	0.46	1.38	4.92	6.92
1-2	8.0	1.1	4.8	54	3.70	1.11	7.41	0.37	1.48	3.89	7.22
2-3	8.1	1.4	5.4	53	5.09	1.70	9.81	0.19	2.08	3.21	11.51
3-4	7.8	1.5	5.0	60	5.67	1.83	9.83	0.33	2.67	2.67	12.33
4-5	8.1	1.4	4.9	48	5.00	1.88	9.17	0.21	2.71	2.29	11.25
5-6	8.2	1.3	4.2	43	4.42	1.86	7.44	0.23	2.56	1.86	9.53
6-7	8.1	1.4	4.8	44	4.09	2.27	8.64	0.23	2.73	2.27	10.23
7-8	8.5	1.3	4.5	29	3.79	2.07	7.59	0.34	2.07	2.07	9.66
8-9	8.7	1.2	4.5	35	3.71	1.71	7.71	0.29	2.00	2.57	8.86
Jg 1C											
0-1	7.4	1.0	1.7	54	4.81	2.04	3.15	0.93	0.37	5.19	5.37
1-2	7.7	0.7	1.9	49	3.27	1.43	2.86	0.20	0.82	3.27	3.67
2-3	7.8	0.6	2.1	45	2.00	1.11	2.67	0.22	0.67	2.89	2.44
3-4	7.9	1.2	5.0	45	2.67	1.78	7.33	0.22	0.67	4.22	7.11
4-5	8.0	2.8	10.3	47	5.11	3.62	21.49	0.43	0.64	3.19	26.81
5-6	7.9	6.1	10.3	45	18.67	14.22	41.78	0.44	0.89	3.56	70.67
6-7	8.0	8.8	15.3	48	19.79	17.50	66.25	0.42	1.04	1.67	101.25
7-8	8.1	8.1	19.9	36	11.11	10.83	65.66	0.28	1.11	3.61	83.06
8-9	8.2	9.7	20.3	45	14.89	16.89	80.67	0.44	0.67	2.22	110.00
9-10	8.3	9.3	20.4	47	14.47	19.15	83.83	0.43	0.64	1.91	115.32
Jg 2											
0-1	8.6	5.0	5.2	71	25.35	15.35	23.38	0.85	2.39	3.94	58.59
1-2	8.0	8.1	14.0	79	22.41	14.43	60.00	0.63	29.24	2.53	65.70
2-3	8.0	9.2	18.0	88	22.73	15.11	77.95	0.57	17.27	3.41	95.68
3-4	8.1	7.7	14.1	70	21.29	11.86	57.43	0.57	5.00	3.00	83.14
4-5	8.2	9.8	19.9	54	20.37	19.44	88.33	0.56	1.11	2.78	124.81
5-6	8.5	14.0	27.5	51	23.33	28.82	140.20	0.78	0.98	2.16	190.00
6-7	8.3	13.9	26.8	71	22.82	29.58	136.71	0.99	0.85	2.25	187.04
7-8	8.6	12.0	27.6	49	18.37	20.00	120.60	0.82	0.82	2.04	156.94
8-9	8.7	9.8	41.6	54	4.93	8.89	109.07	0.56	0.93	3.89	118.52
9-10	8.8	8.6	42.7	42	3.33	6.19	94.29	0.71	1.90	4.76	97.86
Jg 3											
0-1	8.1	1.2	5.6	48	3.13	1.46	8.54	0.21	1.25	5.63	6.46
1-2	8.1	9.2	17.3	65	24.31	19.23	80.46	0.46	11.85	3.85	108.77
2-3	8.2	9.9	21.4	67	20.45	19.40	95.52	0.60	15.22	3.73	117.01
3-4½	8.1	8.7	18.4	63	20.48	17.30	79.84	0.63	4.44	2.70	111.11

Continued.

Table 8. (Continued)

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Jg 4											
0-1	7.8	1.1	3.6	61	4.43	1.80	6.23	0.49	1.15	4.59	7.21
1-2	7.9	1.0	4.8	46	2.83	1.09	6.74	0.22	1.30	4.35	5.22
2-3	7.9	1.2	4.3	42	4.76	1.67	7.62	0.24	1.43	5.24	7.62
3-4	8.4	2.1	5.1	45	7.33	2.67	11.33	0.22	1.78	3.33	16.44
4-5	8.1	2.4	6.0	46	10.00	3.04	14.35	0.22	2.61	3.04	20.22
5-6	8.2	2.7	5.7	58	8.62	4.66	14.66	0.34	2.59	3.45	22.24
6-7	7.9	2.3	5.6	51	6.67	3.73	12.94	0.20	1.76	3.92	17.84
7-8	8.0	1.9	5.4	50	5.60	2.80	11.20	0.20	1.60	4.40	13.80
Jg 4C											
0-1	7.3	0.7	0.5	57	3.33	1.75	0.88	0.70	0.35	4.04	2.28
1-2	7.9	0.4	0.6	53	1.51	0.75	0.75	0.19	0.38	1.13	1.70
2-3	7.9	0.6	0.7	30	2.67	1.67	1.00	0.33	1.00	2.67	2.00
3-4	8.0	0.4	0.8	31	1.94	1.29	0.97	0.32	0.32	2.58	1.61
4-5	8.0	0.4	1.2	35	1.71	1.43	1.43	0.29	0.57	2.57	1.71
5-6	8.0	0.5	1.7	40	1.75	1.25	2.25	0.25	0.50	2.50	2.50
6-7	7.9	0.6	2.4	38	1.84	1.05	2.89	0.26	0.79	3.42	1.84
7-8	8.1	0.7	3.9	38	1.58	0.79	4.21	0.26	0.53	2.63	3.68
8-9	--	--	--	--	--	--	--	--	--	--	--
9-10	8.1	1.0	3.9	46	1.96	2.17	5.65	0.43	0.87	2.17	7.17
Jg 5											
0-1	7.4	1.1	3.5	62	4.03	1.77	5.16	0.65	0.65	5.48	6.29
1-2	8.2	1.8	5.7	51	4.90	2.35	10.98	0.20	1.57	3.33	13.53
2-3	7.8	4.3	3.8	51	27.25	16.27	17.65	0.39	1.37	2.35	57.84
3-4	8.0	5.0	4.8	45	22.89	20.67	22.44	0.44	1.11	2.00	63.33
4-5	8.6	4.0	8.9	53	4.34	15.47	28.11	0.38	1.89	3.40	43.02
5-6	8.4	4.1	11.1	31	7.74	9.68	32.90	0.65	1.94	2.58	46.45
Jg 5C											
0-1	7.7	1.8	6.8	63	4.13	2.54	12.54	0.48	2.06	5.24	12.39
1-2	7.9	8.7	14.4	65	22.77	18.62	65.69	0.62	8.92	3.69	95.08
2-3	7.7	8.4	15.3	73	21.37	13.84	64.11	0.68	8.90	3.70	87.40
3-4	7.7	7.1	13.4	74	20.00	10.41	52.57	0.68	6.22	2.30	75.14
4-5	7.8	5.8	14.5	46	11.30	7.17	44.57	0.65	3.04	2.17	58.48
5-6	7.9	7.3	16.2	38	16.84	11.84	61.05	0.79	2.37	2.11	86.05
6-7	8.1	8.2	18.8	38	15.00	14.74	72.89	0.79	1.58	2.37	99.47

Continued.

Table 8. (Continued)

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Ja 1											
0-1	7.4	0.8	2.2	47	2.80	1.50	3.20	0.41	1.06	3.61	3.19
1-2	7.9	1.0	3.7	44	3.18	1.13	5.45	0.22	1.36	2.50	6.14
2-3	8.4	1.2	3.9	52	3.65	2.12	6.54	0.19	0.77	3.85	7.88
3-4	8.3	1.4	3.9	46	3.04	3.70	7.17	0.22	1.96	3.04	9.13
4-5	8.5	1.8	4.6	35	2.57	2.86	7.71	0.29	1.43	0.29	11.71
5-6	8.2	1.9	4.6	38	4.47	5.53	10.26	0.26	1.58	1.84	17.11
6-7	8.0	5.4	3.5	31	27.10	21.94	17.42	0.98	1.61	2.90	62.90
7-8	8.1	3.5	4.9	25	8.40	36.40	13.60	0.80	2.80	2.40	54.00
8-9	8.1	4.0	3.7	30	16.33	12.33	14.00	1.00	2.00	4.33	37.33
9-10	8.2	4.0	4.2	32	15.94	13.75	16.25	0.94	2.19	2.81	41.86
Ja 2											
0-1	7.9	0.7	2.3	43	3.72	1.40	3.72	0.47	1.86	5.35	2.09
1-2	8.2	1.0	3.9	38	3.68	1.32	6.32	0.26	1.58	3.69	6.32
2-3	8.5	2.1	6.0	51	6.08	4.11	12.55	0.39	1.57	2.94	18.63
3-4	8.5	4.0	5.7	46	7.39	17.60	20.22	0.65	5.65	2.61	15.87
4-5	8.5	2.4	4.2	41	4.39	10.00	11.46	0.73	3.66	2.68	20.24
5-6	8.5	2.6	3.0	37	7.02	10.81	8.92	0.81	1.36	2.70	23.51
6-7	8.1	6.0	3.7	48	26.25	31.25	20.00	2.29	3.13	3.13	73.54
7-8	8.0	5.6	2.6	33	26.36	21.21	12.73	1.21	2.73	1.82	56.97
8-9	8.1	5.1	4.0	30	21.00	17.00	17.33	1.00	1.66	2.66	52.00
Ja 1,2C											
0-1	7.6	0.8	1.7	30	3.33	2.33	2.66	1.00	0.67	5.00	3.33
1-2	8.2	0.4	1.7	29	2.76	2.07	2.76	0.69	0.69	4.83	2.76
2-3	8.4	0.6	11.9	30	1.66	2.33	17.00	0.33	0.67	5.00	15.67
3-4	8.6	0.6	2.0	30	1.00	2.66	2.66	0.33	0.67	4.00	2.00
4-5	8.3	2.5	3.0	29	3.10	9.66	7.59	0.34	8.28	3.45	8.97
5-6	8.0	5.2	6.0	31	10.65	17.10	21.94	0.65	29.35	1.29	19.68
6-7	8.0	8.2	11.3	28	19.64	19.29	50.00	0.71	37.86	1.79	50.00
7-8	8.1	7.5	12.1	32	17.50	16.56	50.31	0.63	25.63	1.56	57.81
8-9	8.0	7.8	10.6	25	20.80	19.60	48.00	0.80	18.40	2.00	68.80
9-10	7.9	9.0	10.4	28	31.07	22.86	53.93	0.71	16.79	2.50	89.29
Ja 3											
0-1	7.9	2.8	7.2	63	8.73	5.08	18.89	0.95	2.22	3.02	28.41
1-2	8.0	7.2	10.0	68	24.56	19.56	47.21	0.59	4.41	2.94	84.56
2-3	8.2	9.5	12.8	56	25.54	27.68	66.25	0.54	5.00	3.04	111.96
3-4	8.4	10.0	14.2	38	23.42	30.26	73.42	0.53	2.89	2.11	132.63
4-5	8.5	7.8	18.6	57	8.42	19.82	70.00	0.70	3.51	2.63	92.80
5-6	8.4	11.6	16.1	76	21.58	26.32	86.71	0.79	3.68	2.37	139.47
6-7	8.5	12.8	17.9	77	22.73	39.09	99.61	0.91	3.25	1.82	157.27
7-8	8.6	13.6	18.7	59	20.68	40.68	103.39	0.85	4.58	3.51	159.15
8-9	8.1	14.0	20.5	56	21.07	40.00	112.68	0.71	4.82	2.32	167.32
9-10	8.5	11.4	16.9	30	21.67	32.00	86.67	1.00	4.00	2.00	135.33

Continued.

Table 8. (Continued)

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Ja 4											
0-1	8.0	2.1	6.0	73	6.03	3.70	13.15	0.55	2.19	3.01	18.22
1-2	7.9	8.0	9.8	69	24.49	15.65	43.91	0.72	6.38	2.61	106.73
2-3	7.9	8.9	12.3	68	23.24	18.09	56.32	0.44	6.62	2.06	89.26
3-4	8.2	9.1	8.1	54	22.59	28.15	40.74	0.56	4.07	--	--
4-5	8.2	7.2	14.9	50	14.60	14.80	57.00	1.20	6.40	4.20	77.00
5-6	8.2	8.3	8.6	58	20.52	26.38	41.72	0.52	5.69	1.72	81.72
6-7	8.4	8.2	14.0	37	16.76	20.54	60.27	1.08	5.95	2.97	89.73
7-8	8.4	4.7	11.1	33	7.27	10.91	33.94	0.61	4.59	3.33	44.24
8-9	7.6	1.5	5.1	50	4.80	2.80	10.00	0.20	1.40	2.40	14.00
9-10	7.7	1.4	4.7	53	4.34	2.83	8.87	0.19	0.75	2.83	1.26
Ja 3, 4C											
0-1	7.5	0.9	1.7	60	2.67	1.50	2.33	0.33	6.00	1.00	5.83
1-2½	7.5	2.7	4.4	49	11.84	6.12	13.27	0.41	0.00	3.88	27.76
Ja 5											
0-1	8.0	1.9	5.5	59	4.75	3.05	10.85	0.85	1.36	3.56	14.58
1-2	8.3	8.0	11.7	57	20.53	19.47	52.46	0.35	4.39	2.63	85.79
2-3	8.2	8.7	12.5	56	20.36	23.39	58.57	0.54	13.04	1.96	87.81
3-4	7.9	8.7	11.5	31	27.10	24.84	58.06	0.32	1.94	2.26	106.13
4-5	8.4	8.7	14.0	31	19.68	24.19	66.13	0.97	3.23	1.94	105.81
5-6	8.4	10.1	16.7	35	20.86	25.43	80.57	0.86	4.86	2.00	120.86
6-7	8.7	13.5	22.3	44	23.64	37.95	123.86	0.91	7.27	1.82	177.27
7-8	8.1	8.1	12.9	31	22.50	16.77	57.10	0.97	6.13	1.94	89.35
8-9	7.6	3.0	13.5	36	3.33	4.17	26.11	0.83	1.11	0.28	33.06
Ja 5, 6C											
0-1	7.5	1.0	3.0	61	3.11	1.64	4.59	0.49	1.15	5.25	3.44
1-2	7.7	5.4	6.8	55	21.32	13.82	28.36	0.55	5.27	3.27	50.49
2-3	7.8	6.5	10.9	55	16.55	14.18	42.73	0.55	5.27	3.27	65.45
3-4	8.0	7.5	10.8	57	18.77	22.28	49.12	0.70	3.33	2.46	85.09
4-5	7.9	7.5	10.3	56	18.75	22.50	46.61	0.71	1.79	2.68	84.11
5-6	8.0	6.2	8.5	39	16.41	16.41	34.36	0.77	1.28	2.56	64.10
6-7	8.1	2.5	12.1	39	3.08	2.82	20.77	0.51	1.79	3.59	21.79
7-8	8.2	2.4	11.2	46	2.39	2.61	17.83	0.43	2.83	3.91	16.52
8-9	8.1	3.7	9.9	63	4.76	4.76	21.59	0.48	1.75	2.22	27.62
Ja 6											
0-1	8.0	1.8	4.9	56	4.82	2.14	9.11	0.54	3.75	3.39	9.46
1-2	8.0	8.3	11.5	47	22.98	18.72	52.55	0.43	8.94	3.62	82.13
2-3	8.2	10.2	13.7	64	23.75	28.13	70.00	0.63	3.13	2.03	117.34
3-4	8.2	10.4	15.6	67	22.84	30.00	80.00	0.60	17.01	1.94	115.82
4-5	8.3	10.3	17.7	74	20.41	25.81	84.86	0.00	7.30	2.16	121.62
5-6	8.3	11.3	20.2	59	23.05	19.49	93.22	0.68	8.81	2.37	125.25
6-7	8.2	10.4	15.6	54	23.70	20.37	73.52	0.93	10.19	2.04	106.30
7-8	8.7	14.3	22.0	44	22.73	40.00	122.50	0.91	7.73	1.14	177.27

Continued.

Table 8. (Continued)

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Ja 6,8C											
0-1	7.7	1.5	6.5	60	3.17	2.17	10.67	0.33	1.83	4.50	10.00
1-2	7.8	9.4	14.1	53	20.74	18.13	62.45	0.57	9.81	3.96	88.30
2-3	8.3	12.0	18.7	39	17.44	35.90	96.41	1.03	--	--	--
3-4	8.3	13.4	24.5	59	21.02	41.53	137.46	0.51	2.71	3.05	194.75
4-5	8.4	19.0	25.0	55	22.73	54.91	155.82	0.55	3.64	4.00	226.36
5-6	8.3	17.5	25.3	52	22.31	49.62	150.77	0.77	3.46	2.69	217.31
6-7	8.6	14.2	22.9	37	19.73	30.27	115.14	0.81	2.70	1.35	161.89
7-8	8.5	12.6	22.6	38	18.95	22.37	102.11	0.79	2.37	2.37	139.47
8-9	8.5	14.0	26.7	43	20.00	26.05	129.07	0.93	2.79	1.63	171.63
9-10	8.4	11.4	21.4	40	19.25	22.50	97.25	1.00	1.75	1.75	136.50
Ja 7											
0-1	8.1	1.6	5.1	69	4.78	2.46	9.86	0.29	1.59	2.32	13.48
1-2	8.0	6.0	6.5	56	24.64	13.04	28.04	0.36	8.75	1.96	55.36
2-3	7.9	4.0	5.7	55	12.00	8.55	18.18	0.55	6.18	0.91	25.30
3-4	8.0	6.1	6.5	50	23.80	15.80	29.00	0.40	2.40	2.00	64.60
4-5	8.4	5.1	22.5	63	4.63	6.35	52.86	0.32	2.22	2.86	59.05
5-6	8.2	7.5	11.0	65	20.00	20.62	49.54	0.62	1.69	2.00	87.08
6-7	8.5	7.2	17.1	73	9.18	13.56	57.67	0.55	2.19	--	--
7-8	8.6	10.8	13.9	76	22.24	23.55	70.00	0.79	2.50	2.24	126.86
8-9	8.7	10.0	16.4	70	20.00	25.43	78.14	0.71	2.43	1.86	120.00
9-10	8.6	11.0	18.2	76	20.92	25.26	37.37	0.79	3.16	1.58	129.60
Ja 7C											
0-1	7.8	0.8	1.5	51	2.35	1.57	2.16	0.39	0.39	2.55	3.53
1-2	8.2	0.6	2.5	38	1.32	1.32	2.89	0.26	0.53	3.95	1.32
2-3	8.2	0.7	3.6	44	1.59	1.14	4.09	0.23	0.68	4.09	2.27
3-4	8.4	2.0	9.1	49	2.24	1.84	12.86	0.20	2.04	2.04	13.06
4-5	--	--	--	--	--	--	--	--	--	--	--
5-6	8.1	7.5	9.6	47	18.30	24.47	44.68	0.64	2.77	2.55	82.77
6-7	8.5	7.2	10.9	51	12.75	20.59	44.51	0.78	2.75	2.55	73.33
7-8	--	--	--	--	--	--	--	--	--	--	--
8-9	8.7	8.5	16.1	48	9.79	23.75	65.63	0.63	1.25	3.54	95.00
9-10	8.6	9.8	18.5	51	10.00	30.39	83.14	0.78	2.94	2.55	113.82
Ja 8											
0-1	8.1	2.0	5.1	100	5.90	2.30	10.40	0.50	2.20	3.50	13.40
1-2	8.0	6.2	10.2	75	20.53	12.40	41.47	0.53	6.80	--	--
2-3	8.0	8.6	13.8	69	23.04	7.97	61.74	0.72	6.96	1.74	94.78
3-4	8.2	7.9	13.8	60	20.00	17.50	59.83	0.67	4.33	2.00	91.67
4-5	8.2	7.6	14.3	58	17.07	18.45	60.17	0.52	3.28	1.72	91.20
5-6	8.3	9.1	14.7	67	21.64	22.99	69.55	0.60	4.63	1.94	108.21
6-7	8.3	9.3	15.9	57	22.46	23.86	76.67	0.88	5.96	17.02	100.88
7-8	8.5	6.8	19.6	58	7.76	11.21	60.34	0.52	5.86	2.41	71.55
8-9	8.3	8.6	12.8	60	22.50	23.00	61.17	0.83	3.83	1.83	101.83
9-10	8.3	8.9	14.0	60	24.17	25.67	69.83	1.00	3.67	1.83	115.17

Continued.

Table 8. (Continued)

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Rm 1											
0-1	7.8	1.5	3.4	55	7.27	2.73	7.64	0.73	1.64	6.18	10.55
1-2	8.0	1.4	3.1	55	5.64	2.36	6.18	0.36	1.82	3.64	9.09
2-3	7.9	1.9	2.8	42	10.00	3.33	7.14	0.48	2.38	3.10	15.48
3-4	8.3	4.4	3.0	45	30.44	15.78	14.22	0.22	4.22	2.44	54.00
4-5	8.1	4.6	4.0	49	23.88	20.41	18.57	0.61	2.24	2.24	58.98
5-6	8.3	9.1	13.6	67	21.94	24.18	64.78	0.90	2.53	2.54	106.72
6-7	8.5	11.6	18.0	74	22.57	25.68	88.51	0.95	2.84	2.30	132.57
7-8	8.4	14.2	20.3	48	25.21	38.75	115.00	1.04	7.08	1.88	171.04
8-9	8.6	14.4	19.3	44	25.23	35.90	106.14	0.91	10.00	1.59	156.59
9-10	8.6	15.5	20.7	47	25.11	33.62	111.91	0.85	9.57	1.91	160.00
Rm 1C											
0-1	7.7	4.2	1.6	38	33.42	23.42	8.42	0.53	6.57	6.58	52.63
1-2	7.7	0.8	4.3	41	6.10	2.68	9.02	0.98	1.22	4.88	12.68
2-3	7.6	5.4	3.8	33	33.64	20.91	19.70	1.21	3.64	4.24	67.58
3-4	7.5	5.2	1.8	38	31.58	19.21	8.95	1.32	3.42	3.42	54.21
4-5	7.4	5.2	1.8	41	34.63	19.51	9.51	1.46	5.12	2.93	57.07
5-6	7.6	5.1	1.9	38	34.47	18.68	9.74	1.05	6.05	2.37	55.53
6-7	7.7	5.6	3.4	40	30.75	18.00	17.00	1.00	6.50	22.00	38.25
7-8	7.7	6.8	4.5	52	25.96	16.54	20.77	0.96	8.27	2.12	53.85
8-9	7.9	8.2	7.6	58	22.41	20.17	35.00	1.03	8.10	2.24	68.28
9-10	8.1	10.2	8.2	42	25.48	23.33	40.24	0.71	6.67	2.38	80.71
Rm 2											
0-1	7.5	1.0	1.2	57	4.21	2.11	2.11	0.53	0.88	6.14	1.93
1-2	7.8	1.0	1.6	47	4.68	2.34	2.98	0.43	1.06	3.19	6.17
2-3	7.9	1.0	1.7	43	6.28	2.56	3.49	0.47	0.93	2.33	9.53
3-4	7.8	1.3	2.3	47	7.87	3.19	5.32	0.64	1.28	4.26	11.49
4-5	7.8	3.4	2.9	59	25.93	8.81	11.86	0.68	0.51	2.54	44.24
5-6	7.9	4.3	3.5	63	27.46	18.10	16.67	0.79	0.63	1.90	60.48
6-7	8.0	4.5	3.4	50	28.00	19.80	16.80	0.80	1.20	3.20	61.00
7-8	8.1	4.6	3.3	51	28.24	19.02	15.69	0.78	1.18	2.75	59.80
8-9	8.1	4.4	3.1	39	26.92	18.46	14.87	0.77	0.77	2.31	57.95
9-10	8.1	4.8	4.3	54	27.22	20.19	20.93	0.74	1.11	2.96	65.00
Rm 2C											
0-1	7.8	0.7	1.3	35	6.29	2.00		0.57	0.57	3.43	7.43
1-2	7.7	1.9	1.4	29	17.93	8.62		0.34	1.03	2.76	27.93
2-3	--	--	--	--	--	--	--	--	--	--	--
3-4	7.6	5.2	4.3	36	29.72	8.89		0.56	2.50	3.33	52.22
4-5	7.6	4.4	1.9	31	33.87	22.26		0.65	3.55	2.26	60.97
4-6	7.5	4.9	1.9	40	35.25	21.75		1.00	4.50	2.50	61.25
6-7	7.6	5.2	2.1	40	31.00	19.25		1.00	5.75	1.50	54.50
7-8	7.6	5.8	3.8	52	28.46	19.81		0.96	7.31	2.31	58.27
8-9	7.7	7.0	6.5	50	24.80	24.00		1.00	8.20	2.40	71.20
9-10	7.9	9.0	7.3	49	22.24	25.10		0.61	7.35	2.24	73.67

Continued



Table 8, (Continued)

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Ra 1											
0-1	7.8	1.4	2.7	57	6.67	2.98	5.96	0.35	1.05	5.26	9.65
1-2	7.9	1.5	3.6	66	6.52	2.73	7.73	0.30	1.36	4.55	11.36
2-3	7.8	3.3	3.0	68	22.42	9.71	11.91	0.59	1.47	3.82	38.68
3-4	7.8	4.3	3.4	55	28.36	15.64	16.00	0.73	2.00	2.73	56.00
4-5	8.0	6.4	5.7	51	25.88	23.33	28.43	0.78	4.90	2.35	71.18
5-6	8.0	8.0	11.0	73	24.38	21.64	55.10	0.82	8.36	3.01	90.55
6-7	--	--	--	--	--	--	--	--	--	--	--
7-8	8.1	9.9	15.0	79	24.56	25.18	74.56	0.89	9.87	4.05	111.27
8-9	8.3	10.4	17.8	58	22.24	25.52	86.72	0.86	8.79	2.93	123.62
9-10	8.5	10.4	18.9	52	19.81	22.88	87.31	0.77	8.27	2.50	120.00
Ra 1C											
0-1	7.7	0.7	0.2	46	6.74	2.61	0.43	1.09	1.30	4.35	5.22
1-2	7.6	1.9	1.6	48	15.21	8.13	5.63	0.83	3.75	3.54	22.50
2-3	7.6	3.8	2.4	43	24.19	18.37	10.93	0.70	4.88	2.33	46.98
3-4	7.8	6.7	5.6	54	23.89	22.78	26.85	0.74	3.89	3.15	67.22
4-5	7.9	6.9	6.5	57	20.88	24.39	30.88	0.88	2.46	2.28	72.28
5-6	8.0	7.3	7.5	42	20.00	20.95	33.81	0.71	2.86	1.90	70.71
6-7	8.0	7.8	7.9	43	22.56	22.79	37.67	0.93	2.79	2.09	79.07
7-8	8.1	7.5	7.5	41	17.32	24.15	33.90	0.98	2.93	1.95	71.46
8-9	8.2	4.5	6.8	39	7.69	8.72	19.49	0.51	2.31	2.56	31.54
9-10	8.2	3.5	6.1	30	7.33	7.00	16.67	0.67	2.33	2.33	27.00
Ra 2											
0-1	7.9	1.5	3.0	53	6.60	3.02	6.60	0.38	1.70	6.04	8.87
1-2	8.0	1.2	3.7	41	4.15	2.20	6.59	0.24	1.95	5.37	5.85
2-3	7.8	4.5	3.6	60	26.50	14.50	16.33	0.67	3.33	2.50	52.17
3-4	7.8	5.0	4.7	63	25.24	16.67	21.59	0.63	2.22	3.33	58.57
4-5	7.9	5.3	6.6	48	26.46	15.42	30.21	0.63	2.92	2.50	67.29
5-6	8.1	6.4	8.1	61	26.56	18.03	38.36	0.66	3.61	2.79	77.21
6-7	8.2	10.8	16.4	49	28.78	27.76	87.76	0.61	6.73	3.47	134.69
7-8	8.3	11.2	21.7	65	24.00	23.08	105.54	0.62	4.92	2.62	145.69
8-9	8.7	10.4	31.7	73	6.99	11.78	97.12	0.55	6.02	4.52	105.89
9-10	8.8	6.4	27.3	79	4.05	7.47	65.44	0.38	3.92	4.18	69.24
Ra 2C											
0-1	7.6	0.6	1.8	33	3.94	1.82	3.03	0.61	1.21	4.24	3.94
1-2	8.0	0.6	2.8	30	2.33	1.33	3.67	0.33	1.00	3.67	3.00
2-3	8.2	1.0	3.6	31	2.90	2.58	5.81	0.32	3.55	3.55	4.52
3-3½	8.1	1.6	2.5	31	9.03	8.06	7.10	0.32	0.97	2.90	20.65
3½-4½	7.8	3.3	2.1	34	21.18	12.94	8.82	0.59	2.06	2.35	39.12
4½-5½	7.9	5.2	3.6	31	21.94	16.77	15.81	0.65	2.58	2.26	50.32
5½-6½	8.2	10.0	8.9	36	24.17	19.44	41.94	0.56	2.78	2.50	80.83
6½-7½	8.4	11.0	3.6	40	19.50	17.25	15.25	0.50	2.50	2.25	47.75
7½-8½	8.3	12.8	2.0	38	18.68	20.00	8.95	0.79	3.16	2.63	42.63
8½-10	8.7	13.0	4.6	38	17.63	16.32	18.95	0.53	3.42	1.84	48.16

Continued.



Table 8. (Continued)

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Ra 3											
0-1	7.7	1.2	2.5	48	6.67	3.13	5.63	0.63	1.46	6.25	8.33
1-2	8.1	1.5	3.3	45	7.56	2.89	7.56	0.22	2.22	4.00	12.00
2-3	8.2	1.2	2.7	43	6.05	1.86	5.35	0.23	1.86	2.79	8.84
3-4	7.8	1.5	2.3	60	8.50	3.33	5.67	0.50	2.17	3.33	12.50
4-5	8.3	2.2	4.5	29	9.31	3.45	11.38	0.34	4.48	3.45	16.55
5-6	8.0	1.6	2.8	41	8.29	2.93	6.34	0.49	2.44	3.17	12.44
6-7	7.1	2.4	5.1	36	10.00	3.89	13.61	0.56	3.61	2.78	21.67
7-8	7.5	2.4	4.7	38	10.26	4.21	12.63	0.53	3.33	2.89	21.32
8-9	8.2	2.1	4.4	36	10.28	4.44	11.94	0.56	1.94	2.78	22.50
9-10	7.9	1.6	2.6	59	9.83	3.39	6.44	0.51	2.88	1.53	15.59
Ra 30											
0-1	7.7	0.8	1.7	41	6.34	9.76	4.88	0.98	0.73	5.37	15.85
1-2	7.9	3.1	2.9	37	18.11	8.38	10.27	0.54	2.97	2.70	31.62
2-3	7.6	3.5	3.6	36	19.72	8.89	13.61	0.56	5.00	2.78	35.00
3-4	7.7	4.2	3.2	42	21.43	10.24	12.86	0.48	6.43	2.38	36.19
4-5	7.8	5.7	4.3	56	17.32	14.82	17.14	0.71	5.36	2.32	38.75
5-6	7.9	5.4	4.7	56	15.18	15.89	18.39	0.89	3.04	2.14	45.00
6-7	8.2	2.1	5.5	26	5.38	11.15	12.69	0.38	2.31	2.69	24.62
7-8	8.4	1.4	5.6	27	3.33	2.59	9.26	0.37	1.48	2.96	11.48
8-9	8.4	1.3	6.7	32	2.19	2.19	9.69	0.63	1.25	3.44	10.00
Ra 4											
0-1	7.6	1.0	1.9	58	7.07	2.59	4.14	0.52	0.86	6.90	6.55
1-2	8.0	1.1	2.5	53	6.04	1.89	4.91	0.19	1.51	4.15	7.36
2-3	8.1	1.5	3.0	52	8.08	2.31	6.73	0.19	2.50	3.27	11.54
3-4	8.0	1.1	2.9	54	5.37	1.67	5.37	0.37	2.04	3.15	7.59
4-5	7.9	1.1	2.5	56	5.00	1.61	4.64	0.36	2.68	4.11	4.82
5-6	8.1	1.6	3.6	48	7.92	2.50	8.13	0.42	2.29	2.50	14.17
6-7	8.3	1.9	4.5	38	8.42	2.89	10.79	0.53	1.59	2.89	18.16
7-8	8.5	1.7	4.1	37	8.11	2.70	9.46	0.27	2.16	2.16	16.22
8-9	8.4	1.7	5.3	33	6.06	2.12	10.61	0.30	2.42	2.73	13.94
Ra 40											
0-1	7.8	1.6	3.5	42	7.38	4.29	8.33	5.24	4.05	5.00	16.19
1-2	7.9	9.3	1.2	38	31.32	25.26	6.58	1.05	53.94	2.11	8.16
2-3	8.0	12.6	4.1	27	25.56	27.41	21.11	0.74	65.19	2.22	7.41
3-4	7.9	6.6	5.0	31	21.61	6.77	18.71	2.26	7.74	2.58	39.03
4-5	8.0	7.1	5.6	40	13.00	10.50	19.25	0.75	4.75	2.00	36.75
5-6	8.4	2.3	9.2	28	2.50	1.79	13.57	0.36	2.14	2.86	13.21
6-7	8.2	1.7	5.7	31	2.90	1.61	8.71	0.97	2.58	2.58	9.03
7-8	8.5	1.0	4.3	33	2.42	1.52	6.06	0.61	0.91	2.42	7.27
8-9	8.2	1.3	3.3	29	5.17	1.72	6.21	0.34	10.69	2.07	10.30
9-10	8.1	2.5	4.4	31	6.13	4.19	10.00	0.97	3.87	1.94	15.48

Continued.

Table 8. (Continued)

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Rg 1											
0-1	7.7	2.1	6.9	62	16.32	5.65	19.52	0.48	2.74	4.03	29.19
1-2	8.0	7.9	11.9	69	22.46	21.59	55.94	0.72	3.48	3.04	94.20
2-3	8.4	10.6	19.5	64	22.03	23.44	92.97	0.94	6.25	4.53	128.59
3-4	8.5	10.2	19.1	72	18.89	5.83	83.75	0.83	3.06	2.78	117.22
4-5	8.8	6.1	23.9	72	5.00	6.81	57.78	0.56	3.47	3.33	63.33
5-6	8.8	3.9	17.7	38	3.68	4.47	35.53	0.53	2.63	3.68	37.89
6-7	--	--	--	--	--	--	--	--	--	--	--
7-8	--	--	--	--	--	--	--	--	--	--	--
8-9	8.9	3.2	23.1	29	1.72	1.38	29.66	0.34	2.41	3.45	27.24
Rg 2											
0-1	7.9	6.2	18.0	66	11.36	8.18	56.36	0.76	6.82	4.55	65.30
1-2	8.6	14.0	27.7	63	19.68	24.29	129.68	0.79	8.89	2.70	162.86
2-3	8.8	16.7	36.7	60	19.00	21.67	165.83	0.67	8.33	3.00	195.83
3-4	9.0	16.5	45.9	74	15.81	16.22	48.51	0.68	6.62	2.43	207.30
4-5	9.1	10.0	52.6	41	2.44	5.37	103.90	0.24	6.10	4.39	101.46
5-6	9.5	16.5	93.7	34	2.06	7.06	199.41	0.59	2.06	7.06	200.00
6-7	9.3	14.6	72.7	74	2.97	8.11	171.36	0.27	2.70	5.54	174.46
No Companion Samples for Rg 1 and Rg 2.											
Rg 2 *											
0-1	7.4	5.3	5.1	64	24.84	13.75	22.50	0.78	4.38	1.88	55.63
1-2	8.3	11.4	20.1	54	4.81	18.33	68.52	0.74	8.52	3.33	80.56
2-3	8.5	14.4	27.5	61	4.59	13.44	82.62	0.66	11.64	2.95	86.72
3-4	9.1	13.4	25.6	71	8.45	8.31	74.23	0.56	7.75	4.51	79.30
Rg 3											
0-1	7.6	1.8	4.8	60	6.00	3.00	10.17	0.33	1.50	1.50	16.50
1-2	7.9	4.6	6.8	55	17.45	13.27	26.73	0.55	3.09	2.91	52.00
2-3	8.3	9.2	12.3	55	20.73	37.64	66.55	0.73	5.40	2.55	113.27
3-4	8.4	9.0	14.0	42	20.24	29.52	69.52	0.71	8.33	2.14	109.52
4-5	8.6	15.0	23.1	61	20.16	48.52	135.08	0.98	13.28	2.46	189.02
5-6	8.8	17.0	24.6	49	20.61	56.33	152.86	1.22	11.43	2.04	217.55
6-7	8.6	13.6	22.7	33	19.39	40.91	124.24	0.91	9.70	18.18	173.94
7-8	8.6	13.6	21.6	37	18.92	31.08	107.57	0.81	7.57	1.89	148.92
8-9	8.6	7.1	21.0	35	8.57	10.86	64.57	0.86	4.29	1.71	78.86
9-10	8.2	6.5	16.6	35	10.00	9.71	52.00	0.57	4.29	2.00	66.00

No Companion Profile for Rg 3.

Continued.

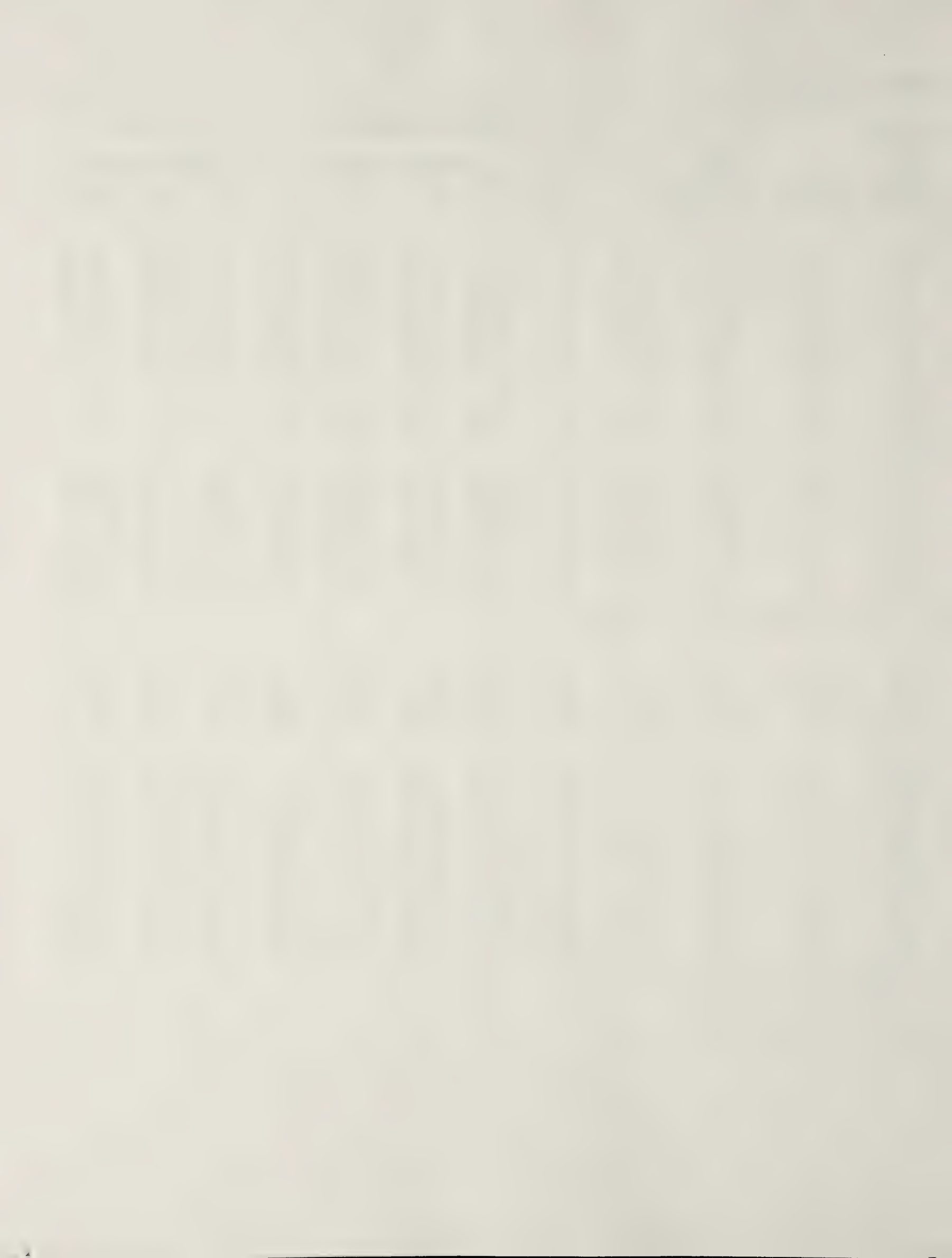


Table 8. (Continued)

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Rg 4											
0-1	7.7	1.3	3.9	56	3.93	2.14	6.61	0.54	0.89	6.07	6.25
1-2	8.2	1.3	4.2	37	4.59	2.16	7.51	0.27	0.81	2.43	11.35
2-3	8.0	2.9	3.6	46	17.61	6.96	12.61	0.43	1.74	2.17	33.70
3-4	8.0	3.6	3.6	43	22.33	12.56	15.12	0.70	2.09	1.86	60.91
4-5	8.1	3.9	4.0	34	23.24	15.88	17.65	0.59	2.06	1.47	53.82
5-6	8.2	5.5	5.4	38	20.26	24.21	25.26	1.05	3.95	1.58	65.26
6-7	8.3	5.6	5.6	46	19.13	28.26	27.17	1.52	3.26	1.30	71.52
7-8	8.2	6.8	7.9	29	18.97	30.69	38.97	1.38	5.86	1.03	83.10
8-9	8.4	4.1	7.4	33	10.91	15.15	26.67	0.91	4.55	3.33	45.75

No Companion Profile for Rg 4.

Rg 5											
0-1	7.7	2.0	4.7	59	7.97	4.24	11.69	0.51	2.88	2.20	19.32
1-2	8.0	4.4	5.7	47	21.49	11.91	23.40	0.43	3.62	2.77	50.85
2-3	8.0	5.2	7.3	56	19.64	17.50	31.25	0.71	6.79	2.32	60.00
3-4	8.1	6.0	9.1	50	20.80	21.00	41.60	0.60	10.40	1.80	71.80
4-5	8.2	5.8	8.6	54	21.11	21.48	39.44	0.74	12.59	2.04	68.15
5-6	8.2	7.2	8.8	56	22.63	26.43	43.57	0.71	15.00	1.79	76.61
6-7	8.1	6.7	9.4	56	16.96	18.39	39.29	0.71	8.39	1.07	65.89
7-8	8.2	7.0	11.6	59	17.29	17.97	48.69	0.85	5.08	1.53	78.14
8-9	7.8	3.9	4.8	32	16.25	6.56	16.25	0.63	2.50	1.25	35.93
9-10	7.8	3.7	0.1	32	14.38	5.63	0.31	0.63	1.88	1.88	17.19

No Companion Profile For Rg 5.

Rg 6											
0-1	7.5	1.2	2.1	51	5.69	2.55	4.31	0.59	1.37	5.29	6.47
1-2	7.8	2.0	2.7	49	9.80	4.29	7.14	0.41	2.24	3.27	16.12
2-3	7.8	2.9	1.7	38	26.58	8.16	6.84	0.26	1.84	2.11	37.89
3-4	7.9	3.3	1.7	48	25.83	11.25	7.50	0.42	1.88	1.88	41.25
4-5	7.9	3.8	2.0	52	27.50	15.77	9.04	0.58	1.54	1.73	49.62
5-6	8.0	4.2	3.0	36	22.50	17.22	13.33	0.56	1.67	1.67	50.28
6-7	8.0	4.2	3.2	44	20.91	16.36	13.64	0.68	2.05	2.95	46.59
7-8	8.1	5.0	3.4	38	21.84	19.74	15.26	0.79	2.89	1.32	53.42
8-9	8.0	5.7	4.0	36	22.78	23.61	19.44	1.11	3.06	1.67	62.22
9-10	8.0	4.4	3.7	26	18.08	15.00	15.00	0.77	2.69	1.54	44.62

No Companion Profile for Rg 6

Continued.

Table 8. (Continued)

Profile and Depth (feet)	pH (paste)	Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Saturation Extract						
					Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Rg 7											
0-1	7.6	1.5	1.9	44	8.41	8.18	5.45	0.68	1.14	6.59	15.00
1-2	8.1	0.8	2.2	32	3.44	1.88	3.44	0.31	1.25	2.50	5.31
2-3	8.2	0.7	2.4	32	2.50	1.25	3.44	0.31	0.94	2.19	4.38
3-4	8.0	1.8	3.5	36	5.56	2.50	6.94	0.56	1.67	2.22	11.67
4-5	8.0	0.9	2.5	23	3.48	1.74	3.91	0.43	0.87	2.61	6.09
5-6	7.8	2.7	1.4	25	19.20	4.80	4.80	0.80	2.00	1.20	26.40
6-7	8.2	0.9	1.6	30	6.33	2.00	3.33	0.33	1.00	1.33	9.67
7-8	8.0	1.2	2.5	30	5.67	2.33	5.00	0.33	1.00	2.00	10.33

No Companion Profile for Rg 7.

Rg 8											
0-1	7.4	1.4	2.2	52	8.08	3.85	5.53	0.58	1.35	3.46	13.27
1-2	7.8	1.6	3.0	46	8.04	3.26	7.17	0.43	1.96	3.48	13.48
2-3	7.9	1.4	2.7	34	6.18	2.35	5.59	0.29	1.47	2.94	10.00
3-4	8.1	1.2	2.8	29	4.83	1.72	5.17	0.34	1.38	2.76	7.93
4-5	8.2	1.2	2.7	30	5.00	1.67	5.00	0.33	1.67	2.67	7.67
5-6	8.2	1.3	2.7	31	6.45	1.94	5.48	0.32	1.61	2.26	10.32
6-7	8.1	1.9	2.6	35	12.57	3.43	7.43	0.29	1.71	2.00	20.00
7-8	8.0	2.6	2.2	32	21.25	5.94	8.13	0.63	2.19	1.56	32.19
8-9	8.0	3.4	2.9	28	20.71	0.36	9.64	0.71	2.86	1.43	27.14
9-10	7.9	3.6	2.2	29	22.07	14.14	9.31	0.69	1.38	1.38	43.45

No Companion Profile for Rg 8.

Ca 1											
0-1	7.6	1.3	3.4	49	6.73	3.67	7.76	0.61	1.22	5.31	12.24
1-2	7.9	0.9	4.8	38	3.42	2.11	8.16	0.26	1.05	3.95	8.95
2-3	7.8	2.7	3.8	45	20.00	7.33	14.00	0.44	1.33	2.44	38.00
3-4	7.9	4.0	4.0	51	26.08	14.51	18.24	0.59	1.18	1.57	56.67
4-5	7.9	4.6	5.6	57	27.19	21.75	27.54	0.53	1.93	1.75	73.33
5-6	8.0	6.0	9.9	41	26.59	31.71	53.66	0.49	5.37	1.71	105.37
6-7	8.1	7.0	9.9	52	26.35	36.15	55.19	0.77	5.96	1.54	110.96
7-8	7.9	7.0	12.5	55	25.64	34.91	69.09	0.91	1.64	1.27	127.64
8-9	7.9	7.0	14.2	58	25.00	30.52	75.17	0.17	7.76	1.72	121.38
9-10	7.9	7.0	20.6	59	23.90	0.34	71.35	1.02	2.37	1.86	93.90

Ca 2											
0-1	8.1	2.0	7.7	53	5.47	6.98	19.25	0.38	2.26	3.58	26.23
1-2	7.7	0.9	5.5	49	3.27	2.36	9.59	0.41	1.63	6.12	8.37
2-3	8.1	5.0	7.8	49	25.31	23.06	37.96	0.61	4.08	1.84	81.02
3-4	8.2	11.0	18.2	35	19.43	46.57	104.00	0.86	12.86	2.00	156.00

Ca 2G											
0-1	7.5	0.8	6.9	46	6.74	8.76	18.91	0.65	0.87	5.87	27.83
1-2	8.4	0.8	10.0	46	1.95	3.26	16.30	0.43	1.30	5.00	15.65

Continued.

Table 8. (Continued)

Profile and Depth (feet)	pH (paste)	Saturation Extract									
		Elect. Cond. (mmhos/cm)	SAR	Sat'n. (%)	Cations (meq/L)				Anions (meq/L)		
					Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Cg 1											
0-1	7.3	1.5	4.3	64	7.66	3.91	10.31	0.78	1.41	7.97	13.28
1-2	7.8	2.9	5.7	61	14.92	7.70	19.34	0.66	3.61	3.93	35.08
2-3	7.9	1.4	4.8	49	28.57	12.45	21.84	0.83	3.88	4.10	63.08
3-4	8.0	4.4	5.8	40	27.25	20.25	28.25	0.50	5.25	5.00	66.00
4-5	8.2	4.6	11.2	35	7.14	39.71	54.29	0.86	13.71	2.00	86.29
5-6	8.3	8.2	9.64	35	19.71	73.14	65.71	1.14	9.71	2.29	147.70
6-7	8.4	10.0	9.01	37	20.27	101.35	70.27	1.08	12.16	2.16	178.65
7-8	8.4	10.0	10.88	38	18.42	84.21	78.94	0.26	7.37	3.95	170.51
8-9	8.4	13.0	8.53	36	18.61	113.61	69.40	1.11	10.28	2.22	190.23
9-10	8.3	1.1	10.28	53	16.60	107.92	81.10	1.32	6.23	2.08	198.63
Cg 2											
0-1	8.0	1.1	4.5	38	5.53	12.89	13.68	0.79	1.84	5.79	13.64
1-2	8.2	0.7	12.8	38	2.11	1.05	16.32	0.26	1.32	4.74	13.68
2-3	8.1	1.5	15.3	40	2.00	1.50	19.75	0.50	3.04	2.75	18.00
3-4	8.3	0.7	4.8	29	2.07	1.38	6.55	0.34	3.45	3.10	3.79
4-5	8.3	0.8	5.2	30	2.00	1.67	7.00	0.33	1.00	3.00	7.00
5-6	8.3	0.8	4.9	37	2.97	2.16	7.84	0.27	1.62	3.51	8.11
6-7	8.1	2.2	4.7	39	10.77	6.15	13.59	0.51	2.56	2.05	26.41
7-8	8.0	3.4	3.7	48	24.38	13.54	16.25	0.63	2.08	1.67	51.04
8-9	8.0	4.0	5.0	44	26.14	18.64	23.41	0.68	7.50	2.05	59.32
9-10	8.0	4.1	4.6	50	26.20	30.40	24.80	1.00	4.60	1.20	76.60
Cg 2C											
0-1	7.6	1.4	1.4	38	7.89	5.53	3.68	6.57	2.63	2.37	18.68
1-2	7.9	1.1	1.7	37	5.41	3.24	3.51	4.05	1.62	4.05	10.54
2-3	7.9	1.6	3.3	37	5.95	4.05	7.30	5.14	2.43	3.24	16.76
3-4	8.1	1.3	2.1	31	2.55	3.87	4.19	2.58	4.84	4.84	4.52
4-5	8.1	0.9	1.4	29	3.10	3.10	2.41	2.41	1.03	2.07	7.93
5-6	8.1	1.1	1.3	35	5.43	4.00	2.86	2.57	1.67	1.71	11.43
Cg 3											
0-1	7.7	0.8	3.0	43	4.88	2.33	5.58	0.47	1.16	5.58	6.51
1-2	7.9	1.0	4.1	41	3.17	2.20	6.59	0.49	1.95	2.68	7.80
2-3	7.9	1.1	5.2	46	3.70	2.39	9.13	0.43	0.87	6.52	8.26
3-4	8.0	1.3	4.8	29	5.86	3.45	10.69	0.34	14.14	3.10	15.83
4-5	8.1	1.2	5.5	30	4.00	3.00	10.33	0.33	2.33	2.67	12.67
5-6	7.9	2.8	5.2	51	14.31	9.80	18.04	0.78	3.14	2.16	37.65
6-7	7.9	4.0	4.7	49	23.47	18.57	21.63	0.82	6.73	1.63	56.12
7-8	8.0	4.0	4.9	48	25.42	28.96	25.83	0.63	15.63	1.46	63.75
8-9	7.9	3.7	4.3	42	22.86	19.29	19.76	0.71	5.00	1.43	56.19
Cg 3C											
0-1	8.0	1.1	2.0	53	5.28	7.17	5.09	0.38	4.52	3.40	10.00
1-2	7.4	0.8	0.6	51	6.27	3.33	1.37	3.92	0.98	5.10	8.82
2-3	7.8	2.0	1.2	48	13.33	12.08	4.38	1.04	7.29	3.33	26.77
3-4	7.9	1.7	1.4	38	11.58	8.16	4.47	1.05	1.32	1.84	22.11
4-5	8.1	0.9	1.7	43	5.12	3.72	3.49	0.70	0.47	1.86	10.70
5-6	8.2	0.7	1.6	31	3.23	2.90	2.90	0.65	0.97	1.29	7.42

Table 9. Chloride concentration ratios in saturation extracts from irrigated soils established under local water management practices, Powder River area, Montana.

Site	Remarks	$(Cl^-)_s$ at 0-1 foot	$(Cl^-)_s$ at 0-1 foot
		$(Cl^-)_s$ at 3-5 feet ²	$(Cl^-)_s$ at >6 feet ¹
Jg 1		0.51	0.51
Jg 1C	rainfall only	0.56	0.33
Jg 4		0.52	0.44
Jg 4C	rainfall only	0.79	0.40
Jg 5		0.43	0.34
Ja 1		0.63	0.38
Ja 7C		0.19	0.13
Rm 1		0.51	0.16
Rm 1C	rainfall only	0.29	0.15
Rm 2	irregular Cl^- distribution	0.98	0.75
Rm 2C	rainfall only	0.19	0.07
Ra 1		0.30	0.11
Ra 2		0.66	0.25
Ra 2C	rainfall only	0.63	0.35
Ra 3		0.44	0.44
Ra 4		0.36	0.36
Rg 4		0.43	0.15
Rg 6		0.80	0.45
Rg 7		0.90	--
Rg 8		0.89	0.47
Ca 1		0.78	0.16
Cg 2		0.89	0.25

1 = The one-foot layer with highest chloride ion concentration below a depth of 6 feet.

2 = Mean of the 3 to 4 and 4 to 5 feet layers where available.

5 feet, followed by other sharp raises in SAR to 27 and 43 below that. Only the surface foot of soil is free from sodicity problems. This indicates that grass roots can be established and a pasture maintained under good water and salt management but the effects of sodic subsoil at a depth of 1 foot on pasture productivity will be very noticeable.

The calcium and sulfate concentrations further indicate that Jg 2 contains free gypsum all through, whereas the upper part of the field does not contain any precipitated gypsum. The water relationships there are satisfactory, whereas those of Jg 2 are probably obstructed at a depth of 1 foot. This situation is further exemplified by the sharp increase in chlorides at 1 foot depth in Jg 2. The chloride content drops again below a depth of 3-4 feet which indicates a small amount of downward movement of water through the profile, perhaps combined with an upward movement of salts by capillary rise from a groundwater table at certain times. The profile shows a balance between downward and upward movement of water and salts which results at present in a precarious 1 foot clearance from salts and sodicity at the surface of profile Jg 2.

Profile Jg 3 was sampled only to a depth of $4\frac{1}{2}$ feet but the evidence within this depth points to an identical situation as in Jg 2. Both soils show strong accumulation of chlorides with a maximum in the main rooting zone which is followed by a decrease in chloride contents in the deeper substrata. The condition is evident from the chloride content ratio of the soil layers shown in Table 10.

Profile Jg 5 shows a less extreme picture. The saturation extract enters into the saline area at 2 feet depth and remains at the same level to the full depth of sampling (6 feet). The soil solution at field capacity would be approximately $EC = 8$ mmhos/cm. The SAR increases with depth but does not assume problematic levels. The cation and anion distributions indicate gypsum precipitation below 2 feet and calcium carbonate precipitation from the surface down. The chloride distribution is at a uniform, low level which suggests satisfactory downward movement of water (Table 8). The chloride ratios shown in Table 9 reflect moderate accumulation at depth. This profile has somewhat coarser textures in the subsurface and subsoil layers than the other 2 sites in the lower portion of the field and has a deeper subsoil consisting of loose sand. This would explain the observed difference. It is assumed that similarly coarse and coarser textures will tend to occur closer to the sandstone outcrops. However, whatever is the distribution of profiles such as Jg 5 in the

Table 10. Chloride concentration ratios in saturation extracts from irrigated soils which have a layer of maximum chloride ion accumulation at a certain depth in the profile (Type 2).

Site	Depth to Maximum Cl ⁻ Concentration (feet)	$\frac{(\text{Cl}^-)_s \text{ at 0-1 foot}}{(\text{Cl}^-)_s \text{ Maximum}}$	$\frac{(\text{Cl}^-)_s \text{ Maximum}}{(\text{Cl}^-)_s >6 \text{ feet}}$
Jg 2	1-2	0.08	31.44
Jg 3	2-3	0.08	--
Jg 5C	1-2	0.23	5.65
Ja 2	3-4	0.33	3.40
Ja 3	2-3	0.44	1.25
Ja 5	2-3	0.10	11.75
Ja 5, 6C	2-3	0.22	3.01
Ja 6	3-4	0.22	2.20
Ja 6, 8C	1-2	0.19	5.61
Ja 7	1-2	0.18	3.60
Ja 8	2-3	0.32	1.90
Ra 3C	3-4	0.11	5.14
Ra 4C	2-3	0.06	16.83
Rg 1	2-3	0.44	2.59
Rg 2	1-2	0.77	4.29
Rg 3	4-5	0.11	3.10
Rg 5	5-6	0.19	7.98
Ca 2	3-4	0.18	--
Cg 1	4-5	0.10	2.20
Cg 3 ¹	3-4	0.08	2.83

1 = Profile containing 2 separate layers of chloride ion accumulation (Type 4).



Haverson soil area, they will be associated with relatively favorable chemical and moisture conditions. It is assumed that profiles Jg 2 and Jg 3 are the more typical of the Haverson area. Such areas will have difficulty with water penetration below the surface layers. There is a possibility that this undesirable condition resulted from consistent under-irrigation of the lower portion of the field. It is also possible, however, that the situation reflects a natural difference between the two soil areas, the upper one of which is more steeply sloping than the other. This explanation is supported by the chemistry of the unirrigated profile Jg 5 which resembles irrigated profiles Jg 2 and 3 rather closely. Regardless of the question as to cause and effect, the proper remedy is improved water management to force larger quantities of water through the lower sections of the field. Narrow borders and large rates of application of irrigation water or perhaps better land leveling should bring relatively larger amounts of water to the lower portion of the field. This will tend to improve the droughty condition as well as the sodicity and saline conditions of the subsoils there with time. These desirable effects will be countered to some extent, however, by the occurrence of the more permeable Jg 5 profiles because these soils will absorb a relatively large share of the additional water applied to the lower areas of the field. Any border strip dominated by Jg 5 profiles would not need the described change in water management.

b. The Jurica alfalfa hay area (Ja).

The alfalfa hay field is entirely located in the Haverson silty clay area according to the soil map with the exception of a small section at the southern extremity. The latter is a silt loam with fairly coarse subsoil textures below a depth of 3-4 feet. Streaks of sandy subsoil occur also further afield in northerly direction, i.e., Ja 5 below a depth of 3 feet. Sandy substrata have considerable effect on the chemical condition of the profile and on possibilities for soil improvement.

The choice of sampling sites is biased in favor of the lower portion of the field. Profile Ja 1 is the only site located in the upper portion. It happens to be a relatively coarse-textured profile with sandy loam below 4 feet. This makes comparison between upper and lower portions of the field rather difficult. Profile Ja 1 does not have any serious problems with regard to water infiltration or downward movement as indicated by low EC values in the upper 6 feet of soil, low SAR values, and low chloride concentrations. Signs

of presence of salinity are expressed in a build-up of chlorides below 6 feet to twice the concentrations occurring in the upper horizons and EC values exceeding 4 mmhos. Precipitated gypsum also is present below this depth as indicated by the high calcium, magnesium and sulfate ion concentrations. The present level of salinity in the substrata does not appear to be damaging to alfalfa yields.

Profiles Ja 2 through Ja 8 represent the lower portion of the field. The EC values indicate considerable accumulations of soluble salts at a shallow depth in the soil (Table 8). The saturation extract of the soil is saline at all sites from the second foot down. Some of the values are high enough to materially affect production of corn, alfalfa, and some grass legume pasture mixtures. The laboratory data for profile Ja 4 show an unusual vertical distribution of salts and exchangeable cations between the first and second foot of soil. It is assumed here that the first and second sample (Lab. Nos. 7267 and 7268) at this site have been inadvertently exchanged in the laboratory.

The chloride concentrations are relatively high and show a several fold increase below a depth of 1 foot (Table 8). The maximum accumulation of chlorides occurs within the main rooting zone between 1 and 4 feet deep and the ratios of chloride contents of the surface layer to that of maximum accumulation vary from 0.44 to 0.10 (Table 10). They suggest a seriously impeded downward movement of water and salts. SAR values also are up sharply at 1 foot and generally keep on rising gradually with increasing depth. The cation and anion concentrations indicate that gypsum and lime precipitation occur below a 12-inch depth or even in the surface soil (Site Ja 3). The presence of free gypsum assists in suppressing the soil pH which otherwise might rise to higher values.

Profile Ja 2 is an exception to most of these observation. It represents Haverson silt loam and therefore has coarser textures. An increase in chlorides and salinity occurs somewhat deeper at 3-foot depth and precipitation of gypsum begins at 4 feet. Such sandy areas have fewer problems with downward water movement than the area in general.

The companion profiles Ja 5,6C and Ja 6,8C, which have not been irrigated, have a chemical condition which is very similar to that of soil after 30 years of irrigation. The EC and SAR values of profile Ja 6,8C below the surface are even higher than those of the irrigated land. This suggests that the irrigation practices and water quality used have not resulted in much deterioration or

improvement of soil conditions. Companion profile Ja 7C is located upslope from the irrigated area. Salinity does not appear in this soil to a depth of 5 feet and sodicity occurs only below 8 feet. The chloride ion distribution shows an accumulation below 3 feet where also gypsum precipitation took place. If this profile were taken as a standard for the original, unirrigated condition of the land, it would appear that considerable deterioration has occurred under irrigation. Land use observations in the area suggest that the alfalfa stand has suffered in the lower portion of the field which has undesirable chemical characteristics in the subsoil. The problem seems to be related to lack of available moisture in the soil. The cause of this droughtiness is the physical condition of the soil. Water penetration and internal drainage are slow due to the near sodic condition of the subsoil. Under-irrigation or lack of penetration in certain parts of the field would have the same final result, namely droughtiness and further deterioration of the soil. Future management will need to emphasize either application of larger quantities of water or a better distribution over the field.

c. The Randall alfalfa hay field (Rm).

The irrigated hay field is situated on Heldt silty clay loam. Interpretation of chemical analyses shows that part of the irrigated area has satisfactory downward movement of water (Profile Rm 2). The chloride ion concentration is low and fairly uniform (Table 8). No build-up of sodium occurs in any part of the profile. There is some salinity below a depth of 4 feet but the concentrations are not limiting to alfalfa production. Profile Rm 1 is somewhat less favorable. The soil extract is saline below 3 feet and the concentrations increase with depth. Below a depth of 6 feet, both salinity and exchangeable sodium are high (Table 8). This condition has a disturbing effect on the water relationships of the soil. The gradual increase in chloride ion concentration from the surface to the bottom of the profile is further evidence of slow water penetration into the subsoil. Although the portion of the field which is represented by Rm 1 needs improved leaching, 5 feet of soil remain relatively problem free. This is sufficient for the present but care should be taken that the subsoil conditions are not raised to the surface.

The companion profiles represent a different soil series and, therefore, cannot be directly compared. Also, it seems that soil sample numbers 7629 and 7630 may have been misplaced in the laboratory. However, it is safe to state that on unirrigated land nearby, the subsoil salinity occurs closer to the

surface than under irrigation, but sodicity has not developed to the same degree as in the lower portion of Profile Rm 1. The ratios of chlorides in soil extracts from surface to lower rooting zone (3-5 feet) for all 4 Rm profiles are presented in Table 9. The values indicate 5 fold differences in chloride accumulation among profiles at 3-5 feet depth and even larger differences in deeper substrata. The situation warrants more attention to proper water management and increased leaching fractions.

d. The Randall alfalfa-grass hay field (Ra).

The alfalfa-grass hay area at the Randall Farm is made up of 3 soil types. The upper portion is Haverson silty clay loam with slopes up to 2%. This is followed by Heldt silty clay loam and finally Haverson silt loam closer to the Powder River and back up along small creek channels. Although the Haverson silt loam generally is more coarse-structured than the Heldt and Haverson silty clay areas, the 2 Profiles Ra 3 and Ra 4 sampled in the Haverson silt loam area are equally fine textured as the others to depths of 2 and 6 feet, respectively. Below that, however, they are relatively coarse-textured. Their accompanying conductivity profiles show absence of salinity (Table 8) whereas those located in the upper part of the field have relatively fine-textured substrata and a gradual build-up of salinity in downward direction with a high peak in the substrata (Ra 1 and 2). The saturation extract of Profile Ra 1 enters the saline category at 3 feet and Ra 2 at 2 feet. The SAR values indicate a sodic condition between 7 and 10-foot depth in Ra 1 and 6 to 10 feet in Ra 2. The chloride and sulfate concentrations indicate a restricted downward water movement and precipitation of lime and gypsum below 2 feet in both profiles. It is to be anticipated that the wild flooding practices will have caused differences in salinity and other ephemeral soil conditions over short distances because the depth of water applied with this method varies from one area to another.

The unirrigated companion Profiles Ra 3C and Ra 4C are much more coarse-textured than their irrigated counterparts. Their chemistry is, therefore, hardly comparable. Despite its coarse texture, Profile Ra 4C shows a high-salinity bulge between 1 and 3 feet below the surface. This is borne out by the electrical conductivity as well as the chloride concentration data (Tables 8 and 10). The salinity increases generally in an upward direction to a peak occurring at a depth of 2 to 3 feet. The situation can be explained by capillary rise in upward direction of water from a high water table and some seasonal downward movement of salts in the upper 1 foot of soil under the

influence of rainfall. The adsorbed sodium which is not quite so readily moved by water peaks between 5 and 6 feet deep in Ra 4C. Profile Ra 3C also shows a balance between upward and downward salt movement with a maximum salt content between 4 and 5 feet.

The chemical composition of companion Profile Ra 1C follows the irrigated site Ra 1 fairly closely to a depth of 5 feet. Coarse sandy textures appear below this depth and are correlated with a sharp reduction in salinity and sodicity compared with Ra 1. The textural profile of Ra 2C is not comparable with that of Ra 2. High ground water tables would result in upward movement of salts which is difficult to correct by improved leaching fractions and other water management factors. Despite the differences in profile characteristics, the vertical distribution of salts is comparable with that of Ra 2 (Table 8) and the chloride accumulation ratios for both profiles are about the same (Table 9).

e. Randall grass hay fields (Rg).

Most of the area consists of Haverson silty clays and silty clay loams. Saline soils occur at the upper end of the fields immediately below the terrace escarpments and valley sides. Some of them are mapped as saline Haverson soils. Normal Haverson soils with clay loam and silty clay loam surface textures take their place toward the Powder River. Salinity and sodicity in these soils are confined to the subsoil but the degree to which the profiles are affected and the depth of overlying soil to the affected layers varies rather widely.

Profiles Rg 1, 2 and 5 are located in the upper part of the fields near the valley slopes and are most affected by salts. Profile Rg 2 is a saline-sodic soil from the surface down as shown by the high values for electrical conductivity and sodium adsorption ratios (Table 8). Also the chlorides are heavily concentrated in the upper five feet of the soil. The companion profile of Rg 2, which is located in the unirrigated area to the north, is affected by salinity and sodicity to almost the same degree. This indicates that the unfavorable soil characteristics are not necessarily caused by irrigation although the irrigation practices used certainly have not improved the condition of the soil over the last 25 years. Profile Rg 1 is salt-affected below 12 inches. The peak values of conductivity, SAR and chlorides occur in the third foot of soil. Soil and water management practices will decide whether the salts will rise closer to the surface or be leached down. The saturation extract of Rg 5 is saline below 12 inches but is not as severely affected as the previous profiles. The SAR values and chloride concentrations increase with depth. Calcium

carbonate and gypsum precipitation has occurred but has not raised the SAR of the saturated soil into the sodic category. The chloride concentrations show a peak at 5 to 6 feet. Water movement through the soil is severely restricted. It will be slow in absorbing water during irrigation and returning quickly to a droughty condition.

Profile Rg 3 is in poor condition. The difference with saline-sodic Profile Rg 2 is in the surface 12 inches of as yet unaffected soil which overlies the site. Profiles Rg 1, 2, 3, and 5 all belong to the salinity Type 2 which is characterized by maximum chloride accumulation within the rooting zone. The depth of maximum chloride accumulation and ratios with chloride contents of layers above and below it are presented in Table 10. Rg 4 has a larger depth of good soil than Rg 3. The saturation extract is saline below 5 feet and marginal between 3 and 5 feet deep. The profile is not seriously affected by sodicity. There is a strong accumulation of chlorides down the profile but the condition is not as severe as at the previous site. Water infiltration at the surface should be satisfactory and there is downward percolation of water. The electrical conductivity of Profile Rg 6 is rather similar to Rg 4 but the SAR values are lower and the chloride distribution is more favorable. The profile is fairly permeable to water.

The southern extremity of the area with profiles 7 and 8 is relatively free from salts. Both soils are coarse textured below the surface layer. Their chemistry suggest no particular problem related to salts. Sites Rg 4, 6, 7, and 8 belong to salinity profile Type 1. The chloride ratios of surface layer to the deeper root zone at 3-5 feet vary between 0.43 and 0.90 (Table 9).

f. The Cook alfalfa and alfalfa-grass area (Ca).

The area consists of silty clay loam of the Heldt and Haverson series. Both soils contain considerable amounts of salt in the subsoil and have a gradual increase in adsorbed sodium with depth. The Heldt soil (Ca 1) is saline below 3 feet and shows a sudden increase in chlorides at a depth of 5 feet which indicates an obstruction in vertical water movement. A sodic condition occurs only in the substrata at a depth of 9 feet. The Haverson soil shows salt accumulation at 2 feet, a sodic subsoil at 3 feet and a rapid accumulation of chlorides in the first 4 feet of the profile, suggesting a seasonal water table at shallow depth. Both soils contain precipitated calcium carbonate and gypsum below the 2-foot depth. Ca 1 remains in the category of normal salinity profile Type 1 (Table 9), whereas Ca 2 falls in Type 2 with much greater accumulation of chlorides at 3-4 feet deep (Table 10).

g. The Cook grass hay area (Cg).

The upper portion of the area is mapped as Heldt silty clay loam whereas the lower portions adjoining the Powder River are Haverson silty clay loam and silty clay types. All sample profiles are relatively coarse textured. Cg 1 consists largely of sandy loam below 3 feet of silty clay loam. The saturation extract is saline below this 3-foot layer and the salt and chloride profiles build up further with depth. The SAR increases to a depth of 5 feet and becomes insignificantly low below that. Profile Cg 2 is coarse-textured to a depth of 7 feet which is atypical for the mapping unit. This portion of the profile is free of salts but displays a sodic condition in the subsurface layer between 1 and 3 feet. There is also a chloride accumulation at this depth (Table 8). The unirrigated companion profile Cg 2 is equally coarse textured and practically free of salts.

Sampling site Cg 3 in Heldt soil is coarse-textured to a depth of 5 feet and is free of salts and alkali to this depth. Below this, the salts accumulate to a borderline salinity level, precipitated calcium carbonate and gypsum are found, and the chloride ion distribution shows a sudden increase. The companion profiles were not sampled to a sufficient depth to verify these trends under unirrigated conditions. Profiles Cg 1 and 3 are classified as salinity Type 2 due to large accumulation of chlorides within the rooting zone (Table 10). Profile Cg 2 shows much less chloride accumulation and belongs to salinity Type 1 (Table 9).

2. The area in general.

The area is characterized by salt-affected soils. The various soil types differ in the degree of development of salinity- and sodicity-related features, but the associated problems for irrigated agricultural production exist and could be aggravated if ignored. At the present time, the undesirable soil conditions are largely underground and confined to the subsoil or deeper substrata. It is considered possible to gradually improve the soil conditions to the point where productivity is not restricted but careful management of soil and water will be necessary to make progress. The land contains large amounts of salts and the water quality of the streams, therefore, is in balance with the condition of the land and also less than optimal. The salt content of the water varies widely during the season and between seasons. It is highly desirable to make use of these fluctuations whenever possible by timing irrigations so as to avoid salinity peaks of the water.

The distinction between normal profiles (Type 1) and those with a maximum accumulation of chlorides in the rooting zone (Type 2) is defined on 3 criteria in this study:

- a. the relative concentration between the surface layer and that of maximum accumulation,
- b. the depth of maximum accumulation, and
- c. absolute concentration of chlorides in the rooting zone.

Type 2 are soils with a 3.33X or more relative concentration of chlorides between the surface and the layer of maximum accumulation, provided the maximum occurs within a depth of 6 feet and including all profiles containing more than 5 milliequivalents per liter of chlorides in the saturation extract within a depth of 5 feet. All soils with a maximum accumulation of chlorides in the second foot below the surface belong to Type 2 (bulge). Those with maximum chloride accumulation between 2 and 3 feet deep are Type 2 also with few exceptions. When the maximum occurs between 4 and 6 feet, the soil may be classified in either category. Most profiles with a maximum below 6 feet belong to the leached groups except those with high chloride concentrations.

It appears from the data presented in Table 11 that in irrigated soils, the chloride accumulation factor in saturated extracts of the surface layer and that of maximum accumulation at whatever depth it may occur, is larger for Type 2 than for Type 1 profiles. The mean value for Type 2 is 6.33X whereas that for Type 1 is 3.76X. This means that the chloride accumulation in Type 2 soils occurs not only at a shallower depth but also is greater. The mean accumulation factor for Type 1 profiles at 3-5 feet is 1.86X (calculated from Table 9). This value is more comparable with that of Type 2 at the same depth in the root zone and further accentuates the difference between Type 1 and 2 profiles.

According to this profile salinity classification, the majority of the sampling sites belongs to Type 2 which is indicative of impeded internal drainage and unsatisfactory penetration of irrigation water into subsurface layers. The bulging profiles of Type 2 may be caused by high seasonal ground water tables in some instances. Under such conditions the chemistry of the soil would tend to improve gradually upon permanent lowering of the high water table. More commonly, the concentration of chlorides in the profile is related to insufficient watering whereby salts accumulate in the rooting zone and to a sodicity problem whereby the relatively high abundance of sodium on the exchange complex causes swelling of the soil and greatly reduced downward percolation of the water.

Table 11. Chloride concentration factors in saturation extracts of soils in the Powder River Valley area.

Site	Type of Profile	Depth of Maximum $(Cl^-)_s$ (feet)	$(Cl^-)_s$ at Maximum $(Cl^-)_s$ at Surface
Jg 1	1	6-7	1.98
Jg 1C	1	7-8	3.00
Jg 2	2	1-2	12.23
Jg 3	2	2-3	12.18
Jg 4	1	4-5	2.27
Jg 4C	1	2-3	2.86
Jg 5	1	--*	2.98
Jg 5C	2	1-2	4.33
Ja 1	1	7-8	2.64
Ja 2	2	3-4	3.04**
Ja 1, 2C	2	6-7	56.51**
Ja 3	2	2-3	2.25**
Ja 4	3	0-1	--
Ja 5	2	2-3	5.59
Ja 5, 6C	2	1-3	4.58
Ja 6	2	3-4	4.54
Ja 6, 7, 8C	2	1-2	5.36
Ja 7	2	1-2	5.50
Ja 7C	2	5-6	7.10
Ja 8	2	2-3	3.16**
Rm 1	1	8-9	6.10
Rm 1C	2	7-8	6.78**
Rm 2	1	3-4	1.45
Rm 2C	1	8-9	14.39

* = Insufficient data.

** = $(Cl^-)_s > 5.0$ meq/L.

Table 11. (Continued).

Site	Type of Profile	Depth of Maximum $(Cl^-)_s$ (feet)	$(Cl^-)_s$ at Maximum $(Cl^-)_s$ at Surface
Ra 1	1	7-8	9.40
Ra 1C	1	3-4	2.99
Ra 2	1	6-7	3.96
Ra 2C	1	2-3	2.93
Ra 3	1	4-5	3.07
Ra 3C	2	3-4	8.81
Ra 4	1	4-5	3.12
Ra 4C	2	2-3	16.10
Rg 1	2	2-3	2.28**
Rg 2	2	2-3	1.22**
Rg 2C	2	2-3	2.66**
Rg 3	2	4-5	8.85
Rg 4	1	7-8	6.58
Rg 5	2	5-6	5.21
Rg 6	1	8-9	2.23
Rg 7	1	5-6	1.75
Rg 8	1	8-9	2.12
Ca 1	1	8-9	6.36
Ca 2	2	3-4	5.69
Cg 1	2	4-5	9.72
Cg 2	1	8-9	4.08
Cg 2C	1	3-4	1.84
Cg 3	2	3-4	13.47

Although more than one-half of the sampling sites occurred in Type 2 soils, the number of Type 1 profiles with normal chloride distribution and the bulging Type 2 are about equal when excluding the unirrigated companion sites. From further inspection, it is believed that the areal extent of properly leached soils of Type 1 dominates in the study area. Interpretation of the soil map and evaluation of sampling site locations led to the estimation that 60 percent of the grassland and 66 percent of the area under alfalfa in the area under investigation consist of Type 1 soils. That is, Type 1 soils dominate most areas with the exception of the alfalfa field at Jurica's ranch and the grassland on Cook's property where Type 1 soils may comprise less than one-third of the total area. The distribution of Type 1 and 2 soils does not appear to be related to the Heldt and Haverson taxonomic series. Instead, it seems that both categories occur in a pattern in most fields. This means that downward moving irrigation water which meets an obstruction in Type 2 soil will percolate through nearby Type 1 sites instead. With time, this will further aggravate the condition of Type 2 profiles because most of the irrigation water applied is absorbed by Type 1 soil. Any water applied as extra leaching fraction will tend to leach the soils which need it less.

The distinction between Type 1 and 2 salinity profiles although of a ephemeral nature, is considered of major importance for irrigation water management and crop production potentialities in the area; more so than differences among taxonomic soil units. It is proposed the Type 1 salinity profiles be considered the most common soil in the area with reference to objective No. 2 of this study and Type 2 the soil with most severe limitations for irrigated agricultural production.

3. Leaching fractions deduced from chloride ion concentrations in soils and irrigation water.

The salt content of soil moisture at field capacity (FC) represents the environment of plant roots more closely than saturation extracts. For this reason, the electrical conductivity (EC), sodium adsorption ratios (SAR) and chloride ion concentrations were converted to field capacity conditions. Actual field capacity measurements were not available so that it was necessary to assume a relationship between the moisture contents at saturation and field capacity. Such a relationship was worked out by Lonkerd and Donovan¹ for some soils in California similar in texture to those along the Powder River.

¹Lonkerd, W. E. and T. J. Donovan. Unpublished data.

The EC, SAR, and chloride ion concentrations so derived were used to calculate leaching percentages, concentration factors and predicted SAR of the soil solution. The results are presented in Tables 12, 13, and 14.

a. Chloride content of irrigation water.

The best estimates of the long-term average chloride contents of the Powder River at Broadus for the months of May, July, and September are 1.09, 1.22 and 0.69 milliequivalents per liter. Assuming that the first irrigation is applied during May, its average chloride content will be 1.09 meq/L. This value is used in calculations relating to fields which are irrigated once during the growing season. The mean of 1.09 and 1.22 meq/L (1.16 meq/L) is applied to fields receiving 2 irrigations per season and the general mean of 1.00 meq/L to 3 irrigations per year.

b. Chloride balance between irrigation water and soil profile.

Irrigation with water of a certain average quality during a number of years brings the soil in equilibrium with the composition of the water. The ratio of the chloride contents of the irrigation water to that of the soil moisture near the bottom of the rooting zone represents the leaching fraction as explained earlier. The data of Table 13 were calculated in this manner for Type 1 profiles at each of the 3 average water qualities and 3 depths in the profile. The 3-foot depth applies to grassland on the assumption that 3 feet is the effective rooting depth of the grass species used for extracting moisture. The mean of the 4th and 5th foot of soil is selected to reflect the depth of rooting of alfalfa under less than optimal conditions. Values are calculated for all water qualities although each field is subjected to only one moisture regime in practice. The mean effective leaching fractions for Type 1 soils under long term use of irrigation water containing 1.09 meq/L of chlorides is 0.41 at 3 feet of depth. The leaching fraction decreases to 0.31 at the 4 to 5-foot depth and to 0.22 when considering deeper substrata.

Table 14 contains similar leaching fractions for Type 2 profiles considering the depth of soil to maximum chloride accumulation. All values are much lower than those for Type 1 soils and have a mean of 0.05. This illustrates adequately the difficulties involved in leaching Type 2 profiles occurring in a pattern with Type 1 soils.

Table 12. Leaching percentages (LP) and concentration factors (CF) calculated from Cl and EC analyses and calculated and predicted SAR of soil solution (drainage water, dw).

Profile and Depth (feet)	LP _{Cl}	LP _{EC}	CF _{Cl}	CF _{EC}	SAR _{dw}	Predicted SAR _{dw}
Jg 1						
0-1	31.9	68.0	3.13	1.47	5.3	5.3
1-2	34.8	87.0	2.87	1.15	6.7	
2-3	25.1	68.5	3.99	1.46	7.5	
3-4	<u>17.7</u>	<u>58.1</u>	<u>5.66</u>	<u>1.72</u>	<u>7.3</u>	
4-5			<u>4.87</u>	<u>1.36</u>	<u>6.6</u>	7.4
5-6			4.38	1.20	5.5	
6-7			4.69	1.30	6.3	6.4
7-8			3.64	1.24	6.0	
8-9			3.30	1.07	5.8	
Jg 2						
0-1	17.1	14.0	5.86	7.12	8.1	8.8
1-2	<u>1.3</u>	8.3	<u>76.61*</u>	12.03	22.7	43.6
2-3	2.2	<u>7.2</u>	<u>45.77</u>	<u>13.88</u>	<u>29.3</u>	33.0
3-4			12.10	10.61	21.9	
4-5			2.15	10.83	27.7	
5-6			1.83	14.91	37.6	
6-7			2.08	19.40	42.0	4.1
7-8			1.49	12.44	37.2	
8-9			1.80	10.82	<u>58.0</u>	
9-10			3.21	8.27	55.5	
Jg 3						
0-1	44.4	81.3	2.25	1.23	7.5	4.6
1-2	3.7	8.4	26.90	11.89	26.1	28.7
2-3	<u>2.8</u>	<u>7.6</u>	<u>35.53</u>	<u>13.14</u>	<u>32.7</u>	
3-4½			9.81	10.95	27.4	
Jg 4						
0-1	40.3	73.5	2.48	1.36	5.3	4.5
1-2	43.7	100.0	2.29	1.00	6.4	
2-3	41.5	86.2	2.41	1.16	5.6	
3-4	32.4	83.3	3.09	1.20	6.7	
4-5	21.8	48.1	4.58	2.08	8.0	
5-6	<u>18.8</u>	<u>31.5</u>	<u>5.33</u>	<u>3.17</u>	<u>8.2</u>	8.1
6-7			3.29	2.45	7.7	
7-8			2.94	1.99	7.3	
Jg 5						
0-1	70.9	73.0	1.41	1.37	5.2	2.5
1-2	34.0	52.1	2.94	1.92	7.8	
2-3	39.1	21.8	2.56	4.58	5.2	
3-4	51.8	<u>20.2</u>	1.93	<u>4.95</u>	6.3	
4-5	<u>27.5</u>	22.9	<u>3.63</u>	4.37	12.3	6.6
5-6			3.29	3.95	<u>14.4</u>	

* = Possible error in Cl data.

_____ = Minimum LP and maximum CF.

Continued.

Table 12. (Continued)

Profile and Depth (feet)	LP _{C1}	LP _{EC}	CF _{C1}	CF _{EC}	SAR _{dw}	Predicted SAR _{dw}
Ja 1						
0-1	77.7	--	1.88	<1	2.9	3.1
1-2	42.7	--	2.34	<1	4.9	4.4
2-3	68.5	81.3	1.46	1.23	5.4	
3-4	29.0	75.2	3.45	1.33	5.7	6.2
4-5	42.4	62.1	2.36	1.61	5.9	
5-6	38.3	58.8	2.61	1.70	5.9	
6-7	36.8	<u>20.2</u>	2.72	<u>4.94</u>	4.6	
7-8	<u>17.7</u>	--	<u>5.65</u>	<u>3.83</u>	<u>7.0</u>	8.2
8-9			<u>3.44</u>	3.72	4.9	
9-10			3.68	3.64	5.4	
Ja 2						
0-1	31.4	--	3.18	<1	3.0	5.4
1-2	38.3	--	2.61	<1	5.0	5.1
2-3	34.0	46.9	2.94	2.13	<u>8.2</u>	
3-4	<u>10.1</u>	<u>26.3</u>	<u>9.92*</u>	<u>3.80</u>	7.6	13.0
4-5	<u>16.4</u>	46.1	6.11	2.17	5.4	
5-6			1.90	2.31	3.8	
6-7	<u>17.8</u>	<u>17.1</u>	<u>5.63</u>	<u>5.84</u>	<u>5.0</u>	
7-8			<u>4.53</u>	<u>5.03</u>	<u>3.35</u>	
8-9			2.86	4.74	5.3	
Ja 3						
0-1	20.4	29.9	4.91	3.35	10.7	7.4
1-2	<u>9.6</u>	10.8	<u>10.45</u>	9.23	15.4	
2-3	10.0	<u>9.7</u>	<u>10.00</u>	<u>10.28</u>	18.1	12.9
3-4			4.77	8.92	18.2	
4-5			7.13	8.57	26.5	
5-6			9.49	16.05	24.3	
6-7			8.43	17.94	28.8	
7-8			9.57	15.38	27.0	
8-9			9.64	15.15	29.0	12.6
9-10			6.88	10.61	22.0	
Ja 4						
0-1	18.2	35.2	5.48	2.84	9.5	8.7
1-2	6.5	9.6	15.31	10.39	15.2	17.1
2-3	<u>6.4</u>	<u>8.8</u>	<u>15.69</u>	<u>11.41</u>	<u>18.9</u>	17.3
3-4			<u>7.90</u>	<u>9.55</u>	<u>11.3</u>	
4-5			11.78	7.17	20.1	
5-6			11.72	9.25	12.3	
6-7			9.76	7.28	17.9	
7-8			7.61	4.22	14.3	
8-9			2.58	1.49	6.9	
9-10			1.44	1.46	6.5	

* = Probable error in C1 data.

Continued.

Table 12. (Continued)

Profile and Depth (feet)	LP _{C1}	LP _{EC}	CF _{C1}	CF _{EC}	SAR _{dw}	Predicted SAR _{dw}
Ja 5						
0-1	35.2	46.5	2.84	2.15	8.0	5.2
1-2	11.2	11.4	8.91	8.79	16.7	
2-3	<u>3.8</u>	<u>10.6</u>	<u>26.08</u>	<u>9.42</u>	<u>17.7</u>	24.0
3-4			3.28	7.95	15.0	
4-5			5.46	7.95	18.2	
5-6			8.02	9.02	21.5	
6-7	<u>8.0</u>	<u>8.0</u>	<u>12.50</u>	<u>12.56</u>	<u>29.3</u>	15.2
7-8			10.36	7.41	16.8	
8-9			1.82	2.66	17.3	
Ja 6						
0-1	13.3	51.3	7.50	1.95	6.9	10.4
1-2	<u>6.3</u>	12.6	<u>15.82</u>	7.95	15.3	
2-3		8.1	7.04	12.42	20.6	
3-4		7.6	39.71*	13.11	23.8	
4-5		<u>7.1</u>	18.47	<u>14.10</u>	28.2	19.7
5-6			18.41	12.78	<u>29.2</u>	
6-7			19.76	10.92	21.7	
7-8			13.29	13.31	28.9	
Ja 7						
0-1	26.2	48.1	3.82	2.08	7.9	6.3
1-2	<u>5.7</u>	<u>15.4</u>	<u>17.50</u>	<u>6.49</u>	<u>9.2</u>	18.9
2-3			11.99	4.26	7.9	
3-4			4.42	6.07	8.8	
4-5			4.91	6.10	--	
5-6			3.84	9.22	16.6	
6-7			5.48	9.74	27.0	
7-8			6.45	15.08	22.3	
8-9			5.89	13.10	25.5	8.8
9-10			8.15	15.36	29.2	
Ja 8						
0-1	18.9	38.5	5.28	2.60	7.9	8.0
1-2	<u>5.8</u>	11.7	<u>17.34</u>	8.56	16.3	19.1
2-3		<u>9.0</u>	16.68	<u>11.17</u>	<u>21.4</u>	18.1
3-4			5.18	9.06	20.1	
4-5			6.76	8.47	20.5	
5-6			10.78	11.47	22.4	
6-7			12.10	10.22	22.7	14.8
7-8			12.07	7.58	28.1	
8-9			8.12	9.86	18.6	
9-10			7.70	10.21	20.4	

* = Probable error in C1 data.

Continued.

Table 12. (Continued)

Profile and Depth (feet)	LP _{C1}	LP _{EC}	CF _{C1}	CF _{EC}	SAR _{dw}	Predicted SAR _{dw}
Rm 1						
0-1	36.0	52.9	2.78	1.89	4.8	4.6
1-2	32.4	56.8	3.09	1.76	4.4	
2-3	28.9	48.8	3.46	2.05	3.6	
3-4	15.8	20.4	6.32	4.89	4.0	8.8
4-5	28.4	18.7	3.52	5.34	5.4	
5-6	19.7	7.4	5.08	13.52	20.8	
6-7	16.2	5.3	6.19	18.73	28.6	
7-8	9.1	6.1	11.03	16.31	27.2	
8-9	6.7	6.3	14.83	15.81	25.3	17.5
9-10	6.8	5.7	14.60	17.51	27.5	
Rm 2						
0-1	64.9	76.9	1.54	1.30	1.7	
1-2	61.7	88.5	1.62	1.13	2.1	
2-3	73.0	91.7	1.37	1.09	2.2	
3-4	51.0	68.0	1.96	1.47	3.1	3.6
4-5	--	22.1	<1	4.53	4.2	
5-6	71.9	16.5	1.39	6.06	5.2	
6-7	45.2	18.9	2.21	5.28	4.6	
7-8	45.5		2.20	5.48	4.5	
8-9			1.28	4.66	4.0	
9-10			2.15	5.94	6.0	

Continued.

Table 12. (Continued)

Profile and Depth (feet)	LP _{C1}	LP _{EC}	CF _{C1}	CF _{EC}	SAR _{dw}	Predicted SAR _{dw}
Ra 1						
0-1	54.3	55.2	1.84	1.81	3.9	3.5
1-2	36.9	45.2	2.71	2.21	5.5	
2-3	33.3	20.0	3.00	4.99	4.6	
3-4	29.4	18.5	3.40	5.41	4.8	5.5
4-5	12.7	13.1	7.89	7.64	7.8	
5-6	5.5	7.8	18.02	12.76	18.2	18.4
6-7	--	--	--	--	--	
7-8	<u>4.5</u>	<u>6.0</u>	<u>22.33</u>	<u>16.55</u>	24.3	21.8
8-9			<u>15.61</u>	<u>13.67</u>	25.6	
9-10			13.47	12.54	<u>26.0</u>	
Ra 2						
0-1	35.6	54.3	2.81	1.84	4.2	4.7
1-2	35.6	78.1	2.81	1.28	4.8	
2-3	16.4	16.4	6.09	6.09	5.2	
3-4	23.6	14.2	4.23	7.05	7.0	6.2
4-5	22.1	16.4	4.53	6.09	8.9	
5-6	14.9	11.3	6.72	8.82	11.9	
6-7	9.5	8.0	10.57	12.54	22.1	17.9
7-8	10.5	6.1	9.54	16.32	32.7	
8-9	<u>7.7</u>	<u>6.0</u>	<u>12.97</u>	<u>16.59</u>	<u>50.1</u>	
9-10			8.85	10.70	44.2	
Ra 3						
0-1	44.1	72.5	2.27	1.38	3.4	3.8
1-2	30.0	59.9	3.33	1.67	4.4	
2-3	36.6	76.3	2.73	1.31	3.5	
3-4	25.2	43.5	3.97	2.03	3.4	
4-5	<u>14.7</u>	<u>40.5</u>	<u>6.78</u>	<u>2.47</u>	<u>6.0</u>	9.3
5-6	<u>28.5</u>	<u>58.8</u>	<u>3.51</u>	<u>1.70</u>	<u>3.6</u>	
6-7	<u>19.6</u>	39.8	<u>5.10</u>	2.51	<u>6.5</u>	5.9
7-8		<u>39.5</u>	<u>4.74</u>	<u>2.53</u>	<u>6.0</u>	
8-9			2.74	2.2	5.6	
9-10			5.19	2.13	3.8	
Ra 4						
0-1	65.4	76.3	1.53	1.31	2.7	2.8
1-2	40.0	74.1	2.50	1.35	3.5	
2-3	24.5	55.2	4.08	1.81	4.1	
3-4	29.3	73.5	3.41	1.36	4.0	
4-5	<u>21.6</u>	71.4	<u>4.62</u>	1.40	3.5	6.6
5-6		54.3	<u>3.55</u>	1.84	4.8	
6-7		<u>50.0</u>	2.26	<u>2.00</u>	5.8	4.5
7-8			3.05	1.78	5.3	
8-9			3.47	1.78	<u>6.8</u>	6.1

Continued.

Table 12. (Continued)

Profile and Depth (feet)	LP _{C1}	LP _{EC}	CF _{C1}	CF _{EC}	SAR _{dw}	Predicted SAR _{dw}
Rg 1						
0-1	19.4	34.5	5.16	2.9	10.2	7.9
1-2	13.9	8.3	7.19	12.09	18.4	9.6
2-3	<u>8.3</u>	6.6	<u>12.10</u>	15.22	29.3	14.5
3-4		<u>6.2</u>	<u>6.55</u>	<u>16.14</u>	30.1	
4-5			7.42	9.65	37.6	9.9
5-6			3.75	4.11	22.7	
8-9			3.65	3.59	30.7	
Rg 2						
0-1	7.4	10.9	13.57	9.14	27.4	15.4
1-2	<u>5.9</u>	5.1	<u>16.84</u>	19.74	41.2	18.2
2-3	<u>6.6</u>	4.4	<u>15.22</u>	22.59	53.4	
3-4	6.9	<u>3.8</u>	14.41	<u>26.64</u>	73.0	16.5
4-5			8.80	<u>10.66</u>	68.0	
5-6			2.93	17.37	120.4	5.2
6-7			5.88	23.57	115.6	
Rg 2 *						
0-1	11.8	17.8	8.48	5.61	7.7	10.2
1-2	7.0	7.1	14.26	14.12	28.0	
2-3	<u>4.6</u>	5.0	<u>21.62</u>	19.85	<u>40.4</u>	21.3
3-4	6.1	<u>4.8</u>	16.35	<u>20.95</u>	40.1	
Rg 3						
0-1	36.5	41.0	2.74	2.44	7.0	4.2
1-2	19.0	17.3	5.25	5.78	9.5	7.8
2-3	10.9	8.7	9.17	11.56	17.3	
3-4	8.2	10.3	12.14	9.71	18.2	
4-5	<u>4.1</u>	<u>4.8</u>	<u>24.67</u>	<u>20.68</u>	<u>34.0</u>	23.3
5-6			17.93	19.74	33.2	
6-7			13.88	14.41	29.3	
7-8			10.70	14.23	27.7	18.2
8-9			6.10	7.48	27.0	
9-10			6.10	6.85	21.3	
Rg 4						
0-1	65.4	60.2	1.53	1.66	5.5	2.9
1-2	87.0	73.5	1.15	1.36	5.4	
2-3	38.0	30.8	2.63	3.25	4.8	4.7
3-4	32.5	25.4	3.08	3.93	4.7	
4-5	34.1	24.3	2.93	4.11	5.1	5.2
5-6	17.8	17.3	5.61	5.79	6.9	
6-7	20.2	15.9	4.95	6.29	7.4	
7-8	<u>11.3</u>	<u>13.1</u>	<u>8.88</u>	<u>7.64</u>	<u>10.5</u>	11.5
8-9			6.51	5.87	9.5	

Continued.

Table 12. (Continued)

Profile and Depth (feet)	LP _{C1}	LP _{EC}	CF _{C1}	CF _{EC}	SAR _{dw}	Predicted SAR _{dw}
Rg 5						
0-1	19.3	37.5	5.18	2.67	6.8	5.9
1-2	18.1	20.1	5.52	4.97	7.6	
2-3	8.5	15.1	11.71	6.64	10.3	
3-4	6.1	14.2	16.50	7.05	12.3	
4-5	4.6	13.9	21.58	7.18	12.0	
5-6	<u>3.9</u>	<u>10.9</u>	25.86*	9.18	12.5	23.8
6-7			14.47	8.55	13.3	
7-8			9.33	9.34	16.8	
8-9			3.62	4.18	6.2	6.6
9-10			2.72	3.97	--	
Rg 6						
0-1	45.2	69.9	2.21	1.43	2.9	3.4
1-2	28.6	43.1	3.50	2.32	3.6	5.3
2-3	38.2	54.1	2.62	1.85	2.2	
3-4	34.4	26.4	2.91	3.79	2.3	
4-5	39.8	21.8	2.51	4.58	2.8	
5-6	42.4	22.7	2.36	4.40	3.8	4.1
6-7	33.0	21.7	3.03	4.61	4.2	
7-8	24.4	19.0	4.10	5.26	4.4	
8-9	23.0	<u>16.8</u>	4.34	<u>5.97</u>	<u>5.1</u>	7.0
9-10	<u>22.4</u>		<u>4.47</u>	<u>5.42</u>	<u>5.1</u>	
Rg 7						
0-1	60.2	60.6	1.66	1.65	2.5	3.0
1-2	55.2	--	1.81	<1	2.9	
2-3	74.1	--	1.35	<1	3.1	
3-4	42.2	53.2	2.37	1.88	4.5	4.4
4-5	58.1	75.8	1.72	1.32	3.8	
5-6	<u>28.7</u>	<u>28.7</u>	<u>3.48</u>	<u>3.48</u>	2.0	5.2
6-7			1.48	<1	2.1	
7-8			1.48	1.31	3.3	
Rg 8						
0-1	45.5	59.2	2.20	1.69	3.0	3.2
1-2	33.7	55.6	2.97	1.80	4.0	
2-3	47.8	68.0	2.09	1.47	3.5	
3-4	40.3	74.1	2.48	1.35	3.7	
4-5	42.7	76.3	2.34	1.31	3.5	4.8
5-6	41.2	71.4	2.43	1.40	3.5	
6-7	41.2	50.0	2.43	2.00	3.3	
7-8	31.5	35.8	3.17	2.79	2.9	
8-9	<u>22.6</u>	25.7	<u>4.42</u>	3.89	<u>3.9</u>	6.5
9-10		<u>24.7</u>	<u>2.09</u>	<u>4.05</u>	<u>2.9</u>	

* = Probable error in C1 data - EC closer.

Continued.

Table 12. (Continued)

Profile and Depth (feet)	LP _{Cl}	LP _{EC}	CF _{Cl}	CF _{EC}	SAR _{dw}	Predicted SAR _{dw}
Ca 1						
0-1	52.4	66.2	1.91	1.51	4.6	3.3
1-2	67.1	--	1.49	--	6.2	
2-3	50.3	33.3	1.99	3.00	5.0	
3-4	52.6	21.0	1.90	4.77	5.5	
4-5	29.7	16.8	3.37	5.96	8.0	
5-6	13.0	15.6	7.72	6.39	12.8	10.8
6-7	10.3	11.8	9.71	8.44	13.6	12.2
7-8	--	11.4	--	8.80	17.5	
8-9	<u>7.3</u>	10.9	<u>13.76</u>	9.20	20.4	15.7
9-10		<u>10.7</u>	<u>4.95</u>	<u>9.34</u>	<u>29.8</u>	
Ca 2						
0-1	39.2	95.2	2.55	1.05	7.4	6.0
1-2	26.8	40.8	3.73	2.45	10.7	
2-3	15.6	17.2	6.41	5.81	10.5	8.8
3-4	<u>5.5</u>	<u>8.6</u>	<u>18.30</u>	<u>11.58</u>	<u>23.4</u>	
Cg 1						
0-1	36.6	46.3	2.73	2.16	6.5	3.6
1-2	14.9	25.1	6.72	3.99	8.4	
2-3	16.4	21.5	6.09	4.65	6.5	
3-4	13.2	21.3	7.56	4.69	7.5	10.0
4-5	<u>5.1</u>	20.7	<u>19.50</u>	4.84	<u>14.4</u>	19.9
5-6	7.2	11.6	<u>13.80</u>	8.64	<u>12.4</u>	
6-7	5.8	9.6	17.19	10.46	11.5	
7-8		9.5	10.42	10.53	14.0	
8-9		<u>7.3</u>	<u>14.53</u>	<u>13.64</u>	10.9	
9-10			<u>10.31</u>	<u>7.02</u>	<u>14.2</u>	
Cg 2						
0-1	38.2	86.2	2.62	1.16	5.8	4.7
1-2	53.2	--	1.88	<1	16.4	
2-3	23.2	62.5	4.31	1.60	<u>19.8</u>	
3-4	<u>19.2</u>	--	<u>5.22</u>	<1	6.4	7.5
4-5			1.48	<1	6.8	
5-6			2.29	<1	6.3	
6-7		42.9	3.66	2.33	6.1	5.9
7-8		25.6	3.22	3.90	5.0	5.3
8-9	<u>9.0</u>	22.8	<u>11.10</u>	4.39	6.6	
9-10		<u>20.8</u>	<u>7.29</u>	<u>4.80</u>	6.2	
Cg 3						
0-1	58.5	--	1.71	<1	3.9	3.2
1-2	35.6	93.5	2.81	1.07	5.3	
2-3	75.8	80.6	1.32	1.24	6.9	
3-4	46.7	68.5	2.14	1.46	6.4	4.1
4-5	28.8	76.3	3.47	1.31	<u>7.2</u>	
5-6	19.8	29.9	5.06	3.34	7.1	
6-7	9.5	<u>21.5</u>	10.56	<u>4.65</u>	6.3	
7-8	<u>4.1</u>	<u>21.8</u>	<u>24.25*</u>	<u>4.59</u>	6.6	22.8
8-9			<u>7.27</u>	3.99	5.6	

* = Possible error in Cl data.

Table 13. Effective leaching fractions on basis of chloride concentration at field capacity established in irrigated soils having generally increasing chloride contents with depth under various water quality conditions (Type 1) and considering three depths of root development.

Site	Average Chloride Ion Concentration in Irrigation Water During Season (meq/L)								
	1.09			1.16			1.00		
	3 ft.	4-5 ft.	>6 ft.	3 ft.	4-5 ft.	>6 ft.	3 ft.	4-5 ft.	>6 ft.
Jg 1	0.33	0.21	0.23	0.35	0.22	0.25	0.30	0.19	0.21
Jg 4	0.45	0.28	0.33	0.48	0.30	0.35	0.41	0.26	0.30
Jg 5	0.43	0.39	0.33*	0.45	0.42	0.35*	0.39	0.36	0.30*
Ja 1	0.75	0.37	0.19	0.79	0.40	0.21	0.68	0.34	0.18
Ra 1	0.31	0.17	0.04	0.33	0.18	0.04	0.29	0.15	0.04
Ra 2	0.15	0.21	0.09	0.16	0.23	0.09	0.14	0.20	0.08
Ra 3	0.34	0.17	0.20	0.37	0.19	0.21	0.32	0.16	0.18
Ra 4	0.23	0.23	0.27	0.25	0.25	0.29	0.21	0.21	0.25
Rm 1	0.27	0.19	0.06	0.29	0.20	0.07	0.25	0.18	0.06
Rm 2	0.69	0.65	0.50	0.73	0.69	0.53	0.63	0.60	0.45
Rg 4	0.36	0.31	0.11	0.38	0.33	0.11	0.33	0.29	0.10
Rg 6	0.36	0.35	0.22	0.38	0.37	0.23	0.33	0.32	0.20
Rg 7	0.69	0.46	0.63	0.74	0.49	0.67	0.64	0.42	0.58
Rg 8	0.45	0.38	0.21	0.48	0.44	0.23	0.41	0.38	0.19
Ca 1	0.47	0.36	0.07	0.50	0.38	0.07	0.43	0.33	0.06
Cg 2	0.22	0.28	0.08	0.23	0.30	0.09	0.20	0.26	0.08
Mean	0.41	0.31	0.22	0.43	0.34	0.24	0.37	0.29	0.20

* = To depth of 5-6 feet only.

Table 14. Effective leaching fractions and chloride concentration factors in irrigated soils having a layer of maximum chloride ion accumulation, calculated on the basis of chloride concentration in the soil solution at field capacity.

Site	Depth of Layer with Maximum (Cl ⁻) Ion Accumulation (feet)	Leaching Fractions at 3 Chloride Ion Concen- trations in Irriga- tion Water (meq/L)			Chloride Concentration Factor in Subsoil
					(Cl ⁻) _{FC maximum} *
		1.09	1.16	1.00	(Cl ⁻) _{FC substratum} **
Jg 2	1-2	0.01	0.02	0.01	51.42
Jg 3	2-3	0.03	0.03	0.03	--
Ja 2	3-4	0.11	0.12	0.10	3.47
Ja 3	2-3	0.11	0.12	0.10	1.19
Ja 5	2-3	0.04	0.04	0.04	14.33
Ja 6	3-4	0.03	0.03	0.03	2.99
Ja 7	1-2	0.06	0.07	0.06	2.97
Ja 8	2-3	0.07	0.07	0.06	2.17
Rg 1	2-3	0.08	0.08	0.07	3.31
Rg 2	1-2	0.06	0.06	0.05	5.75
Rg 3	4-5	0.04	0.04	0.03	4.04
Rg 5	5-6	0.04	0.04	0.03	5.52
Ca 2	3-4	0.05	0.05	0.05	--
Cg 1	4-5	0.05	0.05	0.04	1.89
Cg 3	3-4	0.04	0.05	0.04	2.95
Mean	--	0.05	0.05	0.05	7.85

* = Layer of maximum chloride ion concentration in the profile.

** = Substratum with lowest chloride ion concentration below a depth of 6 feet.

V. Evaluation of Irrigation Practices by Chloride, Conductivity and SAR Analyses.

The soil analytical results were used to evaluate irrigation practices. This evaluation formed a basis for providing water quality evaluations and recommendations. The soil extract data was first transformed from me/100 g to me/l and cross-checked for accuracy and consistency.

Chloride analyses and electrical conductivity of soil extracts and of the irrigation water were used to evaluate the depth to which water was applied and to calculate the average leaching fraction that was applied. In order to do this, soil saturation percentages were calculated to be on a field capacity basis. The soil solution is diluted with distilled water when making pastes and, as a general rule, the soil solution is about twice the concentration and EC of the saturated extract. Since field capacity data was not available for the Montana soils, a regression equation¹ for estimating field capacity from saturated paste percentages for a group of soils similar to those in the study was used for this purpose. A conversion factor (f) was obtained by dividing saturated paste percent (SPP) by field capacity percent (FCP). From this, Cl, EC, and other ions were converted to a field capacity basis. The SAR of the saturated extract (SAR_{se}) was converted to a field capacity basis by multiplying $f^{1/2}$ by each SAR_{se} . This was termed as SAR_{dw} (for drainage water, dw). The (apparent) leaching fraction was calculated two ways: 1) as $LF = Cl_{iw}/Cl_{FC}$, where Cl_{iw} = Cl of irrigation water and Cl_{FC} = Cl of the extract converted to field capacity and, 2) $LF = EC_{iw}/EC_{FC}$. For fields irrigated once a year (Randall and Cook) the average Cl content of the Powder at Moorehead for May (1.16 me/l) was used as Cl_{iw} and average EC for May (1565 μ mhos/cm) was used. For fields irrigated 2-3 times per year (Jurica), the average of May, July and September was used (1.00 me/l Cl and 1850 μ mhos/cm).

The ion concentrations of the irrigation water for May and the average of May, July and September were fed into a computer program developed by Rai and Franklin (1973) and updated and improved by Franklin (1978) along with (part) of the calculated LF and pH of individual soil samples. The program is used to predict equilibrium soil solutions from irrigation water analyses. This predicts lime dissolution or precipitation, gypsum and nesquehonite ($MgCO_3 \cdot 3H_2O$) precipitation, EC, SAR, and ion, ion-pair and total concentrations for a particular LF.

¹Unpublished data.

The calculated LF, CF, SAR_{dw} and Predicted SAR_{dw} from the computer program are shown in Table 12. The LF is shown as the leaching percentage (LP), i.e., $LF \times 100$.

Leaching theory and practical application assumes an equilibrium state. The further the deviation from equilibrium, the greater the uncertainty becomes and the greater the care must be made in the interpretation. Chloride analyses, EC and SAR determinations along with predicted SAR_{dw} were all necessary in the interpretation of this group of soils. The soil analyses clearly indicated soil salinity and sodium problems on part of the soils. High salinity and sodium conditions usually provide a warning of a possible non-equilibrium state. This is not true in all cases, however. The best indications of an equilibrium are when the LP_{Cl} and LP_{EC} give the same minimum value along with the same maximum for CF_{Cl} and CF_{EC} , and when SAR_{dw} closely coincides with Predicted SAR_{dw} , all at the same depth. Then this is the most reliable indication of LF and depth to which the drainage water is passing.

The CF_{EC} (Table 12) usually was smaller than CF_{Cl} in the surface layers probably because of precipitation of lime and/or gypsum. In most cases CF_{EC} and CF_{Cl} tended to agree better with increasing depth. The Cl values were erratic in some cases and were not always reliable. In some cases LP_{EC} and CF_{EC} give a better indication of leaching fraction and depth of water penetration. The good agreement between LP_{Cl} and LP_{EC} , CF_{Cl} and CF_{EC} , and SAR_{dw} with Predicted SAR_{dw} of the Rg 4 profile, as an example, give several indications of reliability. First, it illustrates the equilibrium state. The LP_{Cl} and LP_{EC} are two independently developed criteria, based on water quality factors which may vary considerably. Finally, all things considered, it appears that the average water quality values for Powder River water, some of which were based on estimates from regression equations developed for this study, are realistic and reliable. The low Predicted SAR_{dw} in the 0-1 foot depth probably is related to using (low) pH values reported in the analyses, in part.

Soil analyses showed paste pH's ranging from 7.3 to 8.0 in the 0-1 foot depth. The equilibrium pH in a lime ($CaCO_3$) system exposed to atmospheric carbon dioxide concentrations at 25°C is 8.3. Thus, the use of pH values lower than 8.3 in calcareous soil underpredicts lime precipitation and results in a lower predicted SAR. The equilibrium pH value can run lower than 8.3 in soils containing gypsum, however.

The minimum leaching percentage for both LP_{Cl} and LP_{EC} , maximum concentration factor, (CF_{Cl} and CF_{EC}), and maximum SAR_{dw} are underlined in Table 12 for illustrative purposes. The minimum LP_{Cl} and LP_{EC} agree surprisingly well in most cases, often less than 1 percent difference between the two (independently developed) measures. Most often, minimum LP values occur at the same depth, and the minimum occurs more than a 1 foot depth apart infrequently. Some profiles appear to have more than one minimum LP, separated by a definite trend for higher LP between two minimum values.

Agreement between calculated LP_{Cl} and LP_{EC} in the root zone depths (0-5 feet) is not as good. Precipitation of lime and gypsum overestimates LP_{EC} . Thus, it was concluded that, in general, Cl analyses were the best basis of judging fractions of applied water passing through the root zone but, because of some erratic behavior, Cl analyses were not entirely reliable. Cross-checking between SAR_{dw} and Predicted SAR_{dw} provided a basis for deciding whether or not Cl values were reliable.

Profiles showing a LP of about 5 percent within the crop root zone, considered as less than 4 feet, are Rg 1, Rg 2, Rg 2*, Rg 3, Jg 2, Ja 5. Profiles showing a LP between 6-10 feet are Ca 2, Ja 3, Ja 6, Ja 8, and Ja 4. A LP of about 15 percent is indicated for Ja 7. With the exception of Ja 4, the low LP appears to be directly related to the high sodium content of the subsoil (solonetzic soil). In most cases, both salt and Cl concentrations decrease with depth. These areas were, no doubt, solonetzic before irrigation began and sodium has never been reduced in the lower depths because of the low amount of water penetrating into the soil. Consequently, these areas have never developed the equilibrium state of a normal soil. In fact, it appears from the soil analysis data that not enough water is penetrating into the root zone to meet evapotranspiration demands of the crops. The Ja 4 and possibly the Cg 2 profiles appear to be the only sample areas accumulating salt and exchangeable sodium as a result of consistent under-irrigation (these could be high spots in the field).

The rest of the areas sampled have adequate, if not excessive, amounts of water penetrating into the soil to maintain a salt balance in the root zone.

VI. Evaluation of Irrigation by Water Balance Calculations.

Infiltration rates were determined at 6 sites by means of 12 inch diameter steel infiltrometers. The results in Table 14a show that the infiltration at the

Table 14a. Infiltration rates measured at various sites on the Randall property between May 20 and July 1, 1977 (data collected by YTAPO).

Site	Type of Profile	Infiltration Rate (inches/hour)
Ra 2	I	0.82
Ra 4	I	2.60
Rg 2	II	1.00
Rg 3	II	1.67
Rg 6	I	1.90
Rg 8	I	1.67

Table 15. Water balance for valley soils along the Powder River under current management conditions.

Period	Crop	Consumptive Use (inches)	Effective Rainfall (inches)	Irrigation (inches)	Deficit	To Soil Storage	Remaining Deficit
April 1	Grass	4.50	2.81	--	1.69	-2.22	--
to May 15	Alfalfa	5.17	2.81	--	2.36	-2.22	--
May 16	Grass	8.02	3.32	6.45	--	--	--
to June 30	Alfalfa	9.22	3.32	6.45	--	+0.55	--
July 1	Grass	13.78	1.70	6.45	5.63	--	5.63
to	Alfalfa ¹	11.88	1.70	6.45	3.73	-3.21	0.52
August 31	Alfalfa ²	13.69	1.70	6.45	5.54	-3.21	2.33
September 1	Grass	5.13	2.18	6.45	--	+3.50	--
to	Alfalfa ¹	5.89	2.18	6.45	--	+2.94	--
October 31	Alfalfa ²	5.08	2.18	6.45	--	+3.55	--

¹1 or 2 cuttings.

²3 cuttings.

surface was satisfactory at all sites. Rg 2 and 3 represent Type 2 profiles with an average infiltration rate of 1.34 inches per hour. The four others are Type 1 profiles and average 1.75 inches per hour. If the small difference between the two types may be assumed to be insignificant, the general mean of the infiltration rates is 1.61 inches per hour. This would amount to an average water intake of 6.45 inches during four hours of flooding.

Reference to the calculated actual evapotranspiration values in Table 6 and assuming the dates of first irrigation to be on May 15, second irrigation on July 1 and third irrigation on September 1, it appears that pastures utilize $2.20 + 5.82 = 8.02$ inches of water between first and second irrigation and 13.78 inches between second and third irrigation. Water use by established alfalfa stands between first and second irrigation is 9.22 inches, 11.88 inches between second and third irrigation assuming a second cutting during August, and 13.69 inches without a second cutting.

Both, alfalfa which requires 5.17 inches between April 1 and May 15, and grass requiring 4.50 inches of water can survive without stress during early spring up to mid-May on stored winter precipitation of 1.69 inches supplemented by 3.51 inches of rainfall received between April 1 and May 15.

The moisture holding capacity of the soil varies from one site to another. The mean calculated value for available moisture of the surface 12 inches of all irrigated Randall profiles is 13.86 percent by weight. Those for the next 4 feet are 14.61, 13.44, 13.29, and 12.43, respectively. The first foot of soil will then hold 2.33 inches of available water when assuming a bulk density of 1.40. Similar calculations for the next four 1-foot layers to a depth of 5 feet result in a maximum of 11.36 inches of available stored moisture in the profile at any time during the season. This would be valid for alfalfa. The effective rooting zone (where about 90 percent moisture extraction occurs) of grass pasture may not extend below a depth of 3 feet. The maximum available moisture stored in 3 feet of soil at Randall's is 7.04 inches.

Rainfall taken at 80 percent efficiency of the amounts shown in Table 2 would add 3.32 inches to the available moisture between the first and second irrigation and 1.70 inches between the second and third irrigation. Even light rains will temporarily help to relieve moisture stress on plants but rapid evaporative loss prevents full effectiveness in terms of addition to soil moisture storage. It follows that alfalfa stands would not suffer from drought stress between first and second irrigation provided their roots are developed to a depth of 5 feet (9.77 inches supply, 9.22 inches demand). The one-half inch of surplus water would permit a five percent leaching fraction.

Grass pastures with an effective moisture extraction root zone presumably not extending beyond a depth of 3 feet would not be capable of retrieving all the water applied by irrigation and rainfall (9.77 inches) between the first and second irrigation because the total available water holding capacity is 7.04 inches. With favorable distribution of the rainfall to replenish soil moisture as it is removed, the grass will recover its needs of 8.02 inches leaving approximately 1.75 inches of water for leaching out of the root zone. This would constitute a leaching fraction of 18 percent at a depth of 3 feet.

During the period between the second and third irrigation, the total amount of rainfall and irrigation water would be $6.45 + 1.70 = 8.15$ inches, whereas the water consumption would amount to 13.78 inches for grass pastures, 11.88 for old alfalfa which is cut two or three times and 13.69 inches for alfalfa during the same period when held for seed production after the first

cutting. Here water shortages from 3.73 to 5.63 inches could occur (Table 15). Additional soil moisture from storage in the soil could reduce the deficit for alfalfa to 0.52 to 2.42 inches. Grass roots would not have excess to further stored moisture supply. Several uncertainties enter into the picture here. The soil profile may not have been fully recharged before the start of the growing season. Moisture reserves exceeding maximum storage capacity are possible also when timely rainfall replaces soil moisture already used by the plant. This could provide another 1 inch of water to the crop. Alfalfa used for seed production after the first cutting would still show a $1\frac{1}{2}$ inch water deficit. The consumptive use of alfalfa from which two or three cuttings had been taken, would be sufficiently suppressed to have no water shortage. It should be remembered that all stored water in the soil profile will have been removed at this time.

Another complication is caused by soil heterogeneity. Type 2 salinity profiles do not have normal storage and withdrawal in subsoil layers. Pastures and crops will suffer more severely in such areas than indicated by the previous discussion. This may explain the droughty look and patchy appearance of the fields. On the other hand, Type 1 profiles situated among Type 2 soils may be centers attracting the additional water which cannot penetrate into Type 2 subsoils. This drainage water percolates readily through Type 1 subsoils into the deeper substrata. The chloride profiles of some Type 1 soils, therefore, indicate surprisingly high leaching fractions.

After September 1, there is still a certain amount of consumptive use: 5.13 inches for grassland, 5.89 inches for alfalfa from which one or two cuttings had been taken, and 5.08 inches for alfalfa which is cut once more late in the season (Table 13). An additional irrigation during late August or early September would eliminate all water deficits from then on because the maximum anticipated consumption is only 5.89 inches. Irrigation (6.45 inches) and effective rainfall (2.18 inches) would provide this amount and leave a surplus for leaching in grassland (1.59 inches) below a depth of 3 feet. No water would drain from the alfalfa rooting zone but an appreciable amount of available moisture would remain (2.74 to 3.55 inches) which would contribute to leaching during the next spring.

Without a third irrigation which is the more common in the area, the moisture deficit of the summer months continues through the fall. This analysis is based on the assumption that 6.45 inches of water are applied evenly over the

fields at each irrigation. The leaching fractions indicated by the interpretation are low compared with those derived from interpretation of chloride analysis. The occurrence of high and low spots in the field could explain this because high spots would absorb relatively little water. Management questions arising from this discussion include the possibility of a third irrigation. It appears that profitable ranching as well as good management on lands with pronounced salt problems would be served by a third irrigation at the end of summer. Other obvious improvements in irrigation would result from precision leveling for removal of high spots and depressions, subdivision of fields into narrow borders which would facilitate directing water to the upper or lower end of individual borders as deemed necessary. Furthermore, this would improve control of the water to apply equal amounts of water to various sections of large fields. Finally, narrow borders would assist in parceling off areas dominated by Type 2 soils and forcing extra water down where it is needed most.

VII. Maximum Water Salinity Limits for Crops.

It, at first, might appear that using a better quality water (lower salinity and SAR water) than the Powder River water being used for irrigation of the slowly-permeable solonetzic soils (Type 2 bulge soils) might help to alleviate the salinity and sodium problems. Almost the opposite is true. Lowering the salinity of the water would aggravate the problem. Lowering the SAR while lowering the salinity would help only minimally. The decrease in permeability as the salinity content of water decreases is called the "permeability hazard". The severity of the permeability hazard increases as the clay content, amount of montmorillonite clay, SAR_{dw} and exchangeable sodium percentage (ESP) of the soil or subsoil increases. The permeability hazard of water generally is not serious until the conductivity of the water falls below 500 $\mu\text{mhos/cm}$ (Ayers and Westcot, 1976). However, in the case of highly sodic solonetzic soil this can occur at above 500 $\mu\text{mhos/cm}$. Therefore, it is not recommended that a water with a lower salt content than is used presently be applied for the purpose of improving crop yields on the Type 2 solonetzic (bulge) soil. It is important to use a water with as high a Ca (and Mg) content as possible in order to reduce (replace) the exchangeable Na in the solonetzic soils. Also, a very high volume of water of high Ca water should be passed through the profiles to replace and leach the Na from the root zone.

The most reliable data published for interpreting water quality for a zero decrease in crop yield is found in Ayers (1975) and Ayers and Westcot (1976).

These publications incorporate zero decrease values developed by Maas and Hoffman (1976) who made an exhaustive literature search on the subject and work of other U.S. Salinity Laboratory personnel. The zero yield decrease value, in terms of EC of soil water, for crops in the Powder River alfalfa and grass (orchard-brome and Western wheatgrass) are: brome grass-and-orchard grass, 3.4 mmhos/cm; alfalfa, 4 mmhos/cm; and Western wheatgrass, 10.6 mmhos/cm. These are given for the "average effective root zone" of the crop. For the purpose of this study, the effective root zone of grasses is considered to be 0-3 feet and of alfalfa is 0-5 feet. Average monthly water qualities for the Powder and crop limits for zero yield decrease are summarized in Table 16.

For these generally montmorillonitic clay type soils, the SAR of the soil water should probably never exceed 15. The average SAR of the Powder River water was found to be 2.9, 3.3, and 3.0 for May, July and September, respectively. The slight decrease of SAR in September over July appears to be related to the higher proportion of Clear Creek water in the Powder during September. The average chloride content shows a similar decrease in September, (0.68 me/l) compared to July (1.22 me/l), due to the greater proportion of Clear Creek water. An increase in the SAR_{dw} to 15 over SAR_{iw} would amount to about a five-fold increase, if no lime or gypsum precipitation took place. This would be equivalent to a concentration of irrigation water about 20-25 fold due to evapotranspiration (<5 percent minimum LP). The "normal" irrigated soils (non-solonetzcic) show an average of a two-fold increase in concentration (CF) over the irrigation water in the 0-1 foot depth, based on Cl concentrations. For the 0-3 foot depth the average CF is 2.32 indicating about a 43 percent average LP. An average CF of 2.74 in the 0-5 foot depth indicates a LP of about 36 percent on the average. Using the 0-3 foot average CF for the grasses and the 0-5 foot average for alfalfa, the following EC_{iw} values were found (EC_{sw}/CF):

	EC_{iw}
Orchard-brome	1465 μ mhos/cm
Western wheatgrass	4570 μ mhos/cm
Alfalfa	1460 μ mhos/cm

It would appear that three irrigations with the present quality water used for the Jurica orchard-brome grass field (1850 μ mho/cm average) exceeded the zero yield decrease criteria by a large margin if the CF alone was considered ($1.850 \times 2.32 = 4.29$ mmhos/cm). Lime (and gypsum) precipitate in soils

Table 16. Average monthly Powder River water qualities and crop limits for zero yield decrease.

1. Average Powder River Quality (developed from USGS Quality Data).

	<u>EC - μmhos/cm</u>	<u>SAR</u>	
May	1565	2.9	(1 irrigation)
July	<u>1885</u>	<u>3.3</u>	
Average	1725	3.1	(Average of 2 equal irrigations)
September	<u>2095</u>	<u>3.0</u>	
Average	1850	3.1	(Average of 3 equal irrigations)

2. Limits for Zero Yield Decrease due to Salinity - μ mhos/cm

Crop	<u>EC_{extract}</u>	<u>EC_{soil water}</u>	<u>EC_{irrigation water}</u> ³	<u>EC_{Powder River irrigation water}</u> ⁴
Orchard- Brome	1700 ¹	3400 ¹	1465	<u>1835</u>
Alfalfa	2000 ¹	4000 ¹	1460	<u>1800</u>
Western wheat- grass	5300 ²	10600 ²	4570	<u>5800</u>

¹From: Ayers, R. S. 1975. Interpretation of Quality of Water for Irrigation. FAO, Rome. Irrigation and Drainage Paper No. 16.

²From: Bernstein, L. 1964. Salt Tolerance of Plants. USDA Ag. Inf. Bull. 283.

³Calculated by: $EC_{iw} = EC_{sw}/CF$, where: EC_{sw} = Conductivity of soil water for zero yield decrease; CF = concentration factor = Cl_{sw}/Cl_{iw} or (alternately) ¹Leaching fraction, as determined from Cl analyses; CF = 2.32 for 0-3 root zone of grass, CF = 2.74 for 0-5 root zone for alfalfa (average values for "leached" profiles).

⁴ $EC_{\text{Powder River water}} = EC_{iw}$ corrected for decrease in conductivity by precipitation of salt as lime ($CaCO_3$) and/or gypsum ($CaSO_4 \cdot 2H_2O$).

irrigated with Powder River water in May, July, and September. However, feeding the water quality analyses into the computer program at a LP of 43 ($CF=2.32$), results in a predicted conductivity of 3.6 mmhos/cm and a SAR_{dw} of 5.0. Precipitation of Ca and HCO_3 as lime lowers the conductivity sufficiently to just slightly exceed the zero yield decrease values (3.6 vs. 3.4 mmhos/cm). The yield decrease produced by 0.2 mmho/cm excess would be negligible--probably less than 1 percent and hardly measurable. Three irrigations with waters averaging 1835 μ mhos/cm would be necessary to meet the zero yield decrease criteria. One irrigation with 1565 μ mho/cm water and two irrigations (average 1725 μ mho/cm) easily meet the zero yield decrease criteria when adhering to the calculated leaching fraction and CF. It is highly probable that orchard-brome yields are being decreased to a considerable extent on the solonetzic soils.

It appears that the conductivity of the water used to irrigate the Western wheatgrass on Randall and Cook fields (1 irrigation) could be increased considerably. Assuming that HCO_3 would not increase above 3.5 me/l, (the present July and September water is saturated with respect to lime and this assumption is probably basically correct) and the other ions stayed in the same proportion, the ion concentration of the May irrigation water (17.7 me/l) could be increased about five times to a conductivity of 5800 μ mho/cm with an SAR of 6.0. After further concentration of the water through evapotranspiration by a factor of 2.32 times (43 percent LP), the average 0-3 foot root zone conductivity would be 10.6 mmhos/cm. Alternatively, the leaching percentage could be reduced to about 7.5 percent.

Alfalfa irrigated one time with May quality water (1565 μ mhos/cm) at a LP of 36 percent (concentrated 2.74 times by evapotranspiration) would have an equilibrium average root zone conductivity, after $CaCO_3$ precipitation, equal to 3.6 mmhos/cm. The May quality water would produce a soil water conductivity less than the zero yield decrease threshold value.

Alfalfa irrigated three times with present average water quality (1850 μ mhos/cm) would have a computed root zone soil water averaging 4.2 mmhos/cm. The season average quality (May, July, and September) would have to be reduced to 1800 μ mhos/cm to meet zero yield decrease criteria. The effect of rainfall was not taken into account in establishing zero yield decrease limits. Rainfall tends to dilute the soil solution (soil water) and would tend to cancel small differences found in the above limits (4.2 vs. 4.0 mmhos/cm).

In greenhouse studies of effect of irrigation water quality on alfalfa yields Bernstein and Francois (1973) reported about a 10 percent yield decrease in alfalfa yield from a predominately chloride-anion water with a conductivity of 2000 $\mu\text{mhos/cm}$ as compared with 1000 $\mu\text{mhos/cm}$. Robinson, et al. (1976) reported a slight yield reduction in alfalfa sprinkler irrigated with a 2000 $\mu\text{mho/cm}$ predominately SO_4 , Colorado River water (1450 ppm) compared with 1450 $\mu\text{mho/cm}$ (877 ppm) water in a 3-year study in the Imperial Valley of California. Statistical analysis failed to show statistically significant differences in yields between the two water qualities most of the time.

VIII. Calculation of Maximum Increase in Soil Salinity with High-Salinity Water Application.

The question of how much change can result from one irrigation or several irrigations in one year with unusually high, above average salinity waters was posed in the contractual arrangement. The change in soil EC when irrigation with a water of a given or an assumed EC can be calculated with the following equation: ΔEC = average increase in EC, if soil EC is lower initially, over the given soil depths.

$$\Delta\text{EC}_{\text{sw}} = \frac{D_{\text{iw}} \times \text{EC}_{\text{iw}} \times 100}{D_{\text{s}} \times d_{\text{s}} \times \text{FC}}$$

Where: D_{iw} = depth of irrigation water; D_{s} = depth of soil; EC_{iw} = conductivity of irrigation water; d_{s} = bulk density of soil; and FC = field capacity moisture (%); sw = soil water.

Example 1: For a 3-foot depth of soil (root zone for grass) at wilting point, FC = 26.6, $d_{\text{s}} = 1.4 \text{ g/cc}$, maximum water retention would be about 6.7 inches of water (about the average amount calculated elsewhere in another section). Assuming waters of 3000 and 4000 $\mu\text{mhos/cm}$ were applied (much higher than Powder water in May and July, and only rarely this high in September):

Maximum $\Delta\text{EC}_{\text{sw}} = 1500 \mu\text{mhos}$; $\Delta\text{EC}_{\text{se}} \approx 0.75 \text{ mmhos/cm}$ for 3000 $\mu\text{mho/cm}$ irrigation water.

Maximum $\Delta\text{EC}_{\text{sw}} = 2000 \mu\text{mhos}$; $\Delta\text{EC}_{\text{se}} \approx 1.0 \text{ mmhos/cm}$.

Example 2: For a 5-foot depth of soil (root zone for alfalfa) and other factors remain the same:

(3000 μmho): $\Delta\text{EC}_{\text{sw}} = 900 \mu\text{mhos/cm}$; $\Delta\text{EC}_{\text{se}} \approx 0.45 \text{ mmhos/cm}$.

(4000 μmho): $\Delta\text{EC}_{\text{sw}} = 1200 \mu\text{mhos/cm}$; $\Delta\text{EC}_{\text{se}} \approx 0.60 \text{ mmhos/cm}$.

Example 3: For a 5-foot depth of soil (root zone for alfalfa), assuming the soil was at wilting point, FC = 26.07%, the soil would retain 10.55 inches of H₂O (probably more than is ever applied along the Powder for 1 irrigation according to the information given us).

(3000 μ mho water): $\Delta EC_{sw} = 1500 \mu\text{mhos}$; $\Delta EC_{se} \approx 0.75 \text{ mmhos/cm (Max.)}$.

(4000 μ mho water): $\Delta EC_{sw} = 2000 \mu\text{mhos/cm}$; $\Delta EC_{se} \approx 1.0 \text{ mmho/cm (Max.)}$.

When the soil is at wilting (about one-half of FC), adding just enough water to bring it to FC would cause an (increase) equal to one-half of the EC of the water applied. This indicates an average mixture of the two (soil water and irrigation water). These are fairly extreme examples--rarely does the complete root zone get to wilting point; some capillary water usually will flow into the root zone. Even if the soil water reached a maximum for a zero yield decrease before irrigation, one irrigation would not be enough to cause a 10 percent yield decrease of alfalfa, orchard-brome grass, or Western wheatgrass. Two irrigations under the same assumed conditions with 4000 μ mho water might cause a 10 percent yield reduction for orchard-brome, and three irrigations might exceed a 10 percent decrease. It would probably take three or more irrigations to reach a 10 percent yield decrease for alfalfa under usual irrigation conditions on the Powder. Salt accumulates fairly slowly in fine-textured soils and it has probably taken 15-25 years to reach an "equilibrium" state on most of the irrigated soils in the region.

The main point of the illustrations or examples shown above is that irrigating with high salinity waters occasionally is not going to seriously affect yields. Yields can be decreased 4 to 5 times more if water is not applied and serious water shortages develop.

No doubt yields could be raised by irrigating forage crops three times a year. The economics of this would depend on the conditions and current prices.

IX. Other Water Quality Constituents to Consider in Evaluation of Powder River for Irrigation.

Salinity appears to be the main water quality factor that could be potentially limiting in production of forages along the Powder. Suspended solids could be viewed potentially harmful to crop growth, mainly by siltation of seedlings, and possibly by filling ditches. On the other hand, the suspended solid load probably is very effective in keeping ditch seepage at a minimum in unlined ditches.

The SAR is relatively low most of the time, less than 5. The relatively high salt content acts to reduce any potential "permeability hazard" even under

low leaching conditions. Precipitation of lime and gypsum, even though they occur, do not seem to indicate a problem on "well-leached profiles".

The trace element concentrations of B, Cu, Pb, Zn, Al, Se and Hg, from U.S. Geological Survey Analyses, all are singularly low according to recommended guidelines (Ayers and Westcot, 1976; and others). Thus, no foreseeable hazard from trace elements can be seen unless a dramatic change in quality takes place.

The waters should have a relatively low hazard for sprinkler irrigation. Foliar absorption of Cl and Na by sensitive crops and a decrease in quality of produce due to precipitation of salt on plant material are a few quality-associated hazards in sprinkler applied irrigation. The relatively low Cl and Na contents of the water represent a low-hazard status of this water for the crops now grown. Salt deposition would not be a crop quality decrement for the present crops. The main foreseeable problems associated with possible use of sprinklers are: 1) maintaining a sufficiently high leaching fraction and 2) cleaning sediment from sprinkler pipe.

A criterion not often considered is hazard associated with a nutrient imbalance, such as an unfavorable Ca/Mg balance, where an excess of Mg produces a Ca-deficiency in a crop. This does not appear to be a hazard with Powder River water unless an extremely low leaching fraction were to be used. This is a potential hazard in the Tongue River water.

X. Summary.

A trip to Broadus, Montana was made to inspect the Powder River (and Tongue River) irrigated soil and cropping conditions. Analytical results of soil samples taken by Montana Soil Testing Laboratory at Great Falls were obtained. The analytical results were cross-checked for consistency. Maps where samples were taken were furnished by YTAPO. General interpretations of the profiles were made from soil analysis and map unit.

The soil samples were placed into two groups, one a well-leached group representing generally problem-free soils (Type 1) and a second group containing excessive salts (and Cl) in the root zone and exchangeable sodium increasing with depth (Type 2). The second group of soils were apparently sodic (solonetzic) before irrigation started and constitute problem soils since that time. This problem group did not seem to be associated predominately with either the Haverson or the Heldt soil series.

Irrigation practices were evaluated by deduced leaching fractions, concentration effects, and sodium adsorption ratio of soil water (soil solution).

The Cl, EC and SAR of irrigated soils were converted to a field capacity basis. U.S. Geological Survey Powder River water analyses and flow relations were analyzed to determine a representative monthly water quality average for May, July and September for the period from 1950 to 1975. Leaching fractions and concentration factors were calculated from soil Cl and EC data. Representative water analyses data were entered into a computer program to test equilibrium (steady state) conditions for the leaching percentages, concentration factors, and SAR of drainage water calculated from the data. Minimum leaching percentages in the soil profile, calculated from Cl and from EC agreed surprisingly well. The predicted SAR_{dw} of the well-leached profiles (normal soils) agreed very well with calculated SAR_{dw} but did not agree with the SAR_{dw} of the non-equilibrium sodic (solonchic) soils. A good separation of the two groups was obtained in this way.

Irrigation practices were also evaluated with a water balance approach. Weather data, i.e., temperature, rainfall, wind speed, and solar radiation, were collected. Evapotranspiration was calculated from the weather data. Infiltration rates determined by YTAPO personnel and information on general irrigation practices of farmers in the area, as described by YTAPO personnel, were used to simulate moisture supply from irrigation. One, two, or three 4-hour irrigations, with stored moisture, were balanced against evapotranspiration of grass and alfalfa. This approach indicated a higher irrigation efficiency than did the Cl and EC leaching fraction approach when infiltration rates determined on both Type 1 and 2 soils were used. The water balance approach did not show a large difference between Type 1 and Type 2 soils, but it gave a better picture of irrigation requirement for the crops in the areas.

Values of maximum salinity that can be tolerated for continuous irrigation (zero yield decrease value) of one, two or three irrigations per season were calculated from published values and soil analytical results. Average monthly conductivity values were used with average concentration factors of shallow-rooted grass and deeper-rooted alfalfa to obtain these values. Correction was made for precipitation of lime and/or gypsum but not for the possible alleviating effect of rainfall. Irrigation water of alfalfa and orchard-brome grass pastures was below zero yield decrease limits if one or two irrigations (May and July) were applied. Irrigating three times with average quality water brought alfalfa and orchard-brome grass just slightly beyond the tolerance limit. The tolerance

limit of Western wheatgrass is extremely high so that the present quality waters are well below the zero yield decrease tolerance limit.

Other recommendations concerning water quality factors, of a general nature, were given.

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XII. Appendix.

Table 1. Representative water analyses of Powder River at Morehead, Montana for May, July, and September.

	May	July	September
	<u>me/l</u>		
Ca	6.66	8.31	9.88
Mg	4.13	4.58	5.82
Na	6.65	8.38	8.42
K	0.11	0.16	0.18
HCO ₃	3.17	3.54	3.49
SO ₄	13.25	16.61	20.08
Cl	1.09	1.22	0.68
NO ₃	0.04	0.06	0.05
EC x 10 ⁶	1565 μ hos/cm	1885 μ hos/cm	2095 μ hos/cm
SAR	2.86	3.30	3.00
pH	7.8	7.6	7.7

